THE JOURNAL

OF

"The Royal Aeronautical Society"

with which is incorporated "The Institution of Aeronautical Engineers"

Edited for the Council by Captain J. LAURENCE PRITCHARD, Hon. Fellow

No. 211. JULY, 1928. Vol. XXXII.

NOTICES

Oxford Branch Inaugural Meeting

The Inaugural Meeting of the Oxford Branch was held on June 15th at the Oxford University Air Squadron Headquarters in Manor Road. Mr. J. M. Mitchell, Mr. Ralli and Captain G. S. Wilkinson repeated the lecture on Schneider Trophy Machine Design which they had delivered before the Headquarters of the Society in January. A discussion took place after the three papers had been read, and then the President of the Society, Colonel the Master of Sempill, with whom were Major Kennedy, the Hon. Treasurer, and Mr. L. A. Wingfield, gave a short address on the work of the Branches of the Society. A number of prospective members were enrolled, and Professor Lindemann, F.R.S., President, and Wing Commander A. G. R. Garrod, Hon. Secretary, are to be congratulated on having made a very successful start.

Branches

The President hopes during the course of the present year to visit each branch of the Society and tentative arrangements are being made towards that end.

Members of the Coventry Branch paid a visit to Croydon Aerodrome on June 30th, flying from there to Stagg Lane in an Argosy.

On Saturday, July 14th, a visit has been arranged for members of the Leeds Branch to visit the Howden Airship Station.

Luncheon to Sir Hubert Wilkins

The Councils of the Royal Aeronautical Society, the Royal Aero Club, the Air League of the British Empire, and the Society of British Aircraft Constructors, gave a luncheon to Sir Hubert Wilkins on Wednesday, June 13th, at the Savoy.

Congratulations

The Council cabled congratulations to Captain Kingsford-Smith and his companions on their arrival at Brisbane from San Francisco.

A telegram of congratulation on the successful termination of the Friendship's flight across the Atlantic was sent to Miss Earheart.

Students' Section

The Students' Section of the Society had a very interesting visit to the National Physical Laboratory on Saturday, May 5th.

The Council wish to draw the attention of all students to the importance of taking part in the visits arranged on their behalf. During these visits the students have opportunities of seeing practical methods of construction, research work and the like which they would not otherwise have an opportunity of seeing.

Elections

The Council considered the report of the Grading Committee and the following elections were made:—

Fellow (transferred from Associate Fellow).—Mr. W. E. Dumbrill.
(Transferred from Companion).—Mr. John Lord.
Associate Fellow.—Mr. C. F. Hodson.
Student.—Mr. E. B. de Silva.

Associate Fellowship and Membership Examinations

Provided a sufficient number of entries are obtained the examinations for Associate Fellowship will be held in the week beginning Monday, September 17th, and those for Associate Membership in the week beginning Monday, September 24th. Candidates should advise the Secretary as soon as possible of their intention to take the examination, so that the necessary arrangements can be made.

List of Members

A new list of members is being prepared and in due course every member will be circulated in this connection. It is important that every member should return the slip sent to him as quickly as possible with such corrections as are necessary.

J. Laurence Pritchard, *Secretary.*

OBITUARY

Oliver Henry Douglas Vickers

September 13th, 1898—June 17th, 1928.

The Council with deep regret have to record the death of Captain O. H. D. Vickers, eldest son of Mr. Douglas Vickers, Chairman of Vickers, Ltd. Captain Vickers left Eton at the age of 17 to take up flying. He joined the R.F.C. on his 18th birthday and was sent to France with No. 20 Squadron on June 6th, 1917. He had a distinguished career in France. For a time he was in charge of the Instructional Flight Group at Shotwick and was transferred to the Unemployed List in January, 1919.

He was appointed a special director of Vickers, Ltd., acting as technical adviser to the works at Weybridge. Captain Vickers was a first class engineer with a very wide knowledge of all types of aircraft and his loss will be severely felt.

To Mr. Douglas Vickers and the family the Council offer their sincere sympathy in their loss.

BANQUET TO A. V. ROE, O.B.E., F.R.Ae.S., M.I.Ae.E.

On Friday, June 8th, 1928, a banquet was given by the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, the Royal Aero Club, the Air League of the British Empire, and the Society of British Aircraft Constructors, in honour of A. V. Roe, as a recognition of his pioneer work on machines of his own design and construction, and of the great debt which British aviation owes him.

The chair was taken by Sir Charles Cheers Wakefield, Bt., C.B.E., D.L., J.P., Hon. F.R.Ae.S., and there attended one of the largest gatherings at any aeronautical function of a similar nature, some 400 people being present to welcome Mr. Roe. The company included the Rt. Hon. Sir Samuel Hoare, Bt., C.B.E., C.M.G., M.P., Secretary of State for Air, Air Vice-Marshal Sir John Higgins, K.B.E., K.C.B., D.S.O., A.F.C., Air Member for Supply and Research, Sir Edward Crowe, C.M.G., Comptroller-General, Department of Overseas Trade, the leading designers and pioneers in the aircraft industry, representatives of foreign Governments and the Councils of the four bodies controlling British aviation.

The Chairman, in proposing the toast of Mr. Roe, pointed out that this was an occasion of great importance in the history of British aviation. He paid a tribute to Mr. Roe's modesty and inventive genius, and gave a brief history of his achievements since the day in 1902 when he built his first model aeroplane. Sir Charles Wakefield paid a deserved tribute, too, to those who had worked side by side with Mr. Roe, his brother H. V. Roe, Mr. Lord, Mr. Parrott and Mr. Chadwick, to bring about the success which was now his.

The Chairman read a few of the many telegrams which had been received. These included messages of congratulation from the Aeronautical Society of Germany, the Aero Club of France, the French Ministre du Commerce et de l'Industrie (Aeronautique et Transports Aériens), Harry F. Guggenheim, of the Daniel Guggenheim Fund for the Promotion of Aeronautics, and pioneers who were unable to be present.

Mr. Roe, in the course of his reply to the toast of honour, stated that his first real achievement was to win the chief prize offered by the *Daily Mail* in 1906 for power-driven model aeroplanes. Then followed years of experiments, successes and failures, side by side with other pioneers, and in 1912 came the first enclosed aeroplane to fly in the world, a small monoplane with an air-cooled radial engine, followed by an enclosed biplane, and the tractor biplane which to-day is the most widely used type in the world.

The banquet was followed by a dance at which H.R.H. the Duke of York, Patron of the Royal Aeronautical Society, was present. H.R.H. took the opportunity to talk at length with many who were presented to him by the President, Colonel the Master of Sempill.

Each lady present was given a lasting memento of the occasion in the form of a gilt vanity box engraved with the initials of Mr. A. V. Roe and those of the four bodies giving the banquet.

The success of the evening and the smoothness of the arrangements were due to the untiring energy and personal efforts of the President, Colonel the Master of Sempill.

List of Guests.

J. B. Abraham, Esq., Mrs. Abraham, Captain P. D. Acland, Mrs. Acland, Flight-Lieut. R. E. H. Allen, M.I.Ae.E., Wing-Commander W. H. Anderson, D.F.C., Major Atkinson, Mrs. Atkinson, Commander Awaya, Keith Ayling, Esq.

Howard Back, Esq., Mrs. Back, Major B. F. S. Baden-Powell, Hon. F.R.Ae.S., Captain H. Balfour, R. M. Balston, Esq., B. Banks, Esq., Mrs. Banks, Major T. M. Barlow, F.R.Ae.S., Mrs. Barlow, G. Barnett, Esq., A. J. Wallace Barr, Esq., Mrs. Wallace Barr, F. S. Barnwell, O.B.E., A.F.C., F.R.Ae.S., Lieut.-Colonel J. Barrett-Lennard, F. C. Bayliss, Esq., Mrs. Bayliss, Major E. G. E. Beaumont, O.B.E., Major K. M. Beaumont, Mrs. Beaumont, Captain L. M. Beck-Friis, R.S.N., L. E. R. Bellairs, Miss Benger, A. E. Berriman, Esq., O.B.E., F.R.Ae.S., Miss Birkett, Wing-Commander H. Blackburn, A.F.R.Ae.S., Mrs. H. Blackburn, R. Blackburn, Esq., F.R.Ae.S., Mrs. R. Blackburn, Miss E. F. Blackmore, Major W. T. Blake, A.M.I.Ae.E., F.R.G.S., E. M. Boote, Esq., the Hon. Sybil Borthwick, Lieut. de Vaisseau Bos, the Hon. A. R. Boyle, A.F.R.Ae.S., Major H. G. Brackley, D.S.O., D.F.C., Mrs. Brackley, Captain W. Brass, M.P., A. Bray, Esq., Group Captain E. F. Briggs, D.S.O., O.B.E., A.F.R.Ae.S., Mrs. Broad, R. A. Bruce, Esq., M.Inst.C.E., M.I.Mech.E., A.F.R.Ae.S., Mrs. Bruce, the Hon. Mrs. Victor Bruce, Major J. S. Buchanan, O.B.E., F.R.Ae.S., A.M.I.Mech.E., Mrs. Buchanan, Major G. P. Bulman, O.B.E., A.F.R.Ae.S., Flight-Lieut. P. W. S. Bulman, A.F.R.Ae.S., Mrs. Bulman, H. Burroughes, Esq., Mrs. Burroughes.

— Cardew, Esq., Captain L. W. Charley, O.B.E., Mrs. Charley, R. Chadwick, Esq., A.F.R.Ae.S., Mrs. R. Chadwick, F. Martin Chisholm, Esq., A. E. L. Chorlton, Esq., C.B.E., Senor J. de la Cierva, F. J. Cleveland, Esq., A.M.I.Ae.E., Mrs. F. J. Cleveland, Miss Cleveland, C. G. Colebrook, Esq., Mrs. C. G. Colebrook, Major J. B. C. Cooper, O.B.E., Mrs. J. B. C. Cooper, Miss V. M. Cooper, — Crossley, Esq., Sir Edward Crowe, C.M.G., Lady Crowe, Miss P. Crowe.

R. Dangerfield, Esq., Captain E. Keith Davies, A.F.R.Ae.S., A.M.I.A.E., F. A. Davies, Esq., Mrs. F. A. Davies, Captain R. Bell Davies, V.C., D.S.O., A.F.C., Mrs. Bell Davies, W. S. Davidson, Esq., Colonel I. Dayson, F. G. T. Dawson, Esq., Mrs. F. G. T. Dawson, Captain de Havilland, O.B.E., F.R.Ae.S., M. Desoutter, Esq., Miss Jeanne Desoutter, — Dixon, Esq., A. C. Donaldson, Esq., Commander H. F. Dons, G. Dorman, Esq., Mrs. G. Dorman, Mrs. Dreschfield, Dr. A. E. Dunstan, Mrs. A. E. Dunstan, W. Dutton, Esq.

— Eastwood, Esq., Guy Eden, Esq., E. C. Gordon England, Esq., A.F.R.Ae.S., Mrs. Gordon England, James Erskine, Esq., Keith Erskine, Esq., Representative of *Exchange Telegraph Co.*

C. R. Fairey, Esq., F.R.Ae.S., Mrs. C. R. Fairey, A. H. R. Fedden, Esq., F.R.Ae.S., Mrs. A. H. R. Fedden, Lieut.-Colonel L. F. R. Fell, D.S.O., O.B.E., M.I.Mech.E., F.R.Ae.S., Mrs Fell, W. Fenton, Esq., Brig.-General Festing, C.B., C.M.G., Mrs. Festing, H. Guy-Iffiske, Esq., H. P. Folland, Esq., F.R.Ae.S., M.I.Ae.S., Captain Forsyth, Mrs. Forsyth, Philip Foster, Esq., Mrs. Frisby.

C. J. Galpin, Esq., Mrs. Galpin, Miss M. Garratt, Air Commodore Gerrard, Mrs. Gerrard, A. H. Gilling, Esq., Miss Gooch, Alan Goodfellow, Esq., Miss Sybil Gore, Claude Grahame-White, Esq., Mrs. Grahame-White, C. G. Grey, Esq., Major F. M. Green, A.M.Inst.C.E., F.R.Ae.S., Mrs. F. M. Green, P. T. Griffith, Esq., A.F.R.Ae.S., Mrs. P. T. Griffith, Mrs. P. R. C. Groves and Party, Don M. Grove, Mrs. Grove, Captain the Right Hon. F. E. Guest, P.C., C.B.E., D.S.C., M.P., K. Lee Guinness, Esq., Mrs. Lee Guinness.

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Lieut.-Colonel F. H. Neish, C. Nicoreanu, Esq., Miss Nicoreanu, J. D. North, Esq., F.R.Ae.S., Mrs. North.

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Handley Page, Esq., C.B.E., F.R.Ae.S., Mrs. Handley Page, J. Parker, Esq., Lankester Parker, Esq., Hedley Parlett, Esq., C. G. Parnall, Esq., R. J. Parrott, Esq., Mrs. Parrott, Lieut.-Commander J. Paster, Miss Mary Perfect, R. Perfect, Esq., Commander H. E. Perrin, — Perrin, Esq., Major — Petre, Sir Ernest Petter, Lady Petter, Squadron-Leader Pettingell, R. K. Pierson, Esq., A.M.Inst.C.E., F.R.Ae.S., T. St. John Plevins, Esq., Mrs. Plevins, *Press Association*, Lieut. R. E. Preston, J. Laurence Pritchard, Esq., Hon. F.R.Ae.S., Mrs. Pritchard, Mrs. Purchase, H. C. Puttick, Esq.

Miss M. Quelch.

Commander C. Rachlew, R.N.N., F. P. Raynham, Esq., Mrs. Raynham, Squadron-Leader G. H. Reid, D.F.C., M.I.Ae.E., Mrs. Reid, W. F. Reid, Esq., F.R.Ae.S., Miss N. Rennie, R. Rhodes, Esq., A.M.I.Ae.E., Mrs. Rhodes, Miss A. Rhodes, Miss J. Rhodes, Major F. A. de V. Robertson, M.A., A. V. Roe,

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F. E. N. St. Barbe, Esq., Miss O. St. Barbe, Miss M. Sambrook, Lieut.-Colonel H. J. Sanders, D.S.O., M.C., Mrs. Sanders, W. P. Savage, Esq., A.F.R.Ae.S., Mrs. Savage, Captain W. H. Sayers, Flight-Lieutenant E. R. C. Scholefield, A.F.C., D.C.M., Mrs. Scholefield, — Schweder, Esq., Mrs. Schweder, F. P. Scott, Esq., Mrs. Scott, J. W. Seddon, Esq., S. J. Selby, Esq., C.B.E., A.F.R.Ae.S., Miss F. M. Selby, Mr. B. Stevenson, Colonel the Master of Sempill, A.F.C., A.F.R.Ae.S., President, R.Ae.S.I., V. Ker-Seymer, G. F. Sharp, Esq., R. H. Sharp, Esq., Captain Shiozawa, Oswald Short, Esq., J. D. Siddeley, Esq., E. H. Siddeley, Esq., Mrs. E. H. Siddeley, F. R. Simms, Esq., A.M.I.Mech.E., M.I.A.E., M.I.Ae.E., Major S. V. Sippe, Stanley Spooner, Esq., Stanhope Sprigg, Esq. (Airways), Major O. Stewart, R. Stiles, Esq., Mrs. Stiles, Captain R. H. Stocken, A.M.I.Ae.E., Dr. Marie C. Stopes, D.Sc., Ph.D., F.L.S., F.R.S.L., Miss Store, Miss W. Stott, Miss Strachen, Sir Thomas Strangman, Lady Strangman, Captain C. G. Sturt, A.F.C., A.F.R.Ae.S., Rear-Admiral M. F. Sueter, R.N., C.B., M.P., Mrs. Sueter, Miss Sueter, Miss Willa Sueter, J. Suthering, Esq., Sir Oliver Swann, K.C.B., C.B.E., Lady Swann, H. J. Stieger, Esq., D.I.C., A.F.R.Ae.S.

J. C. C. Taylor, Esq., Mrs. J. C. C. Taylor, — Tegner, Esq., Mrs. Tegner, Dr. F. B. Thole, T. B. Thomas, Esq., Mrs. Thomas, Lieut.-Colonel N. G. Thwaites, C.B.E., M.V.O., M.C., Representative of *The Times*, Miss M. Todd, Miss Vera Tolhurst, Mrs. Alec Tweedie.

Flight-Lieut. C. F. Uwins.

The Very Rev. Vance, H. T. Vane, Esq., C.B.E., Mrs. Vane, Miss Veasey, General R. Verduzio, Mrs. Verduzio, M. M. Vergara, Esq., Captain O. Vickers, G. R. Volkert, Esq., A.F.R.Ae.S., Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O., Lady Vyvyan.

Sir Charles C. Wakefield, Bart., C.B.E., Lady Wakefield, C. C. Walker, Esq., A.M.Inst.C.E., F.R.Ae.S., Mrs. Walker, T. W. Ward, Esq., Captain L. Warner, Mrs. Warner, Fiddes Watt, Esq., Dr. H. C. Watts, D.Sc., F.R.Ae.S., Miss D. M. Weale, Admiral Sir Richard Webb, K.C.M.G., C.B., Lady Webb, Air Commodore J. G. Weir, Mrs. Weir, Sir Henry White-Smith, Miss White-Smith, Captain Wilkinson, Mrs. Wilkinson, Hollis Williams, Esq., Flight-Lieut. W. T. S. Williams, D.S.C., Mrs. Williams, Captain C. B. Wilson, C. W. Wimbury, Esq., Lawrence Wingfield, Esq., Mrs. Wingfield, C. G. H. W. Winter, Esq., Lady Wiseman, R. McKinnon Wood, Esq., Mrs. McKinnon Wood, Mrs. M. Woode, S. R. Worley, Esq., Major Maurice Wright, Mrs. Maurice Wright, Miss Wykes.

Commander Yamasita.

Miss Anna Zinkheisen.

PROCEEDINGS

EIGHTH MEETING, SECOND HALF, 63RD SESSION

The eighth meeting of the second half of the 63rd Session of the Royal Aeronautical Society was held in the rooms of the Royal Society of Arts, John Street, Adelphi, London, W.C.2, on Thursday, April 12th, 1928, when a paper by Dr. H. S. Hele-Shaw, D.Sc., F.R.S., and Mr. T. E. Beacham, B.Sc., on "The Variable Pitch Airscrew" was read and discussed. Colonel the Master of Sempill (President of the Society) presided.

The CHAIRMAN, in calling upon Dr. Hele-Shaw to present the paper, said that it was quite unnecessary to introduce him, for he was so well known for his work in connection with every branch of engineering. When looking into his life history one's eyes were dazzled by reading of the number of gold medals he had received, of the list of societies over which he had presided, and of the honours which had been showered upon him by technical bodies in this and other countries. Dr. Hele-Shaw was a senior Whitworth Scholar in 1876; he is the only man to have received the Gold Medal of the Institution of Naval Architects, although not then a member of that body. Dr. Hele-Shaw was at one time President of the Institution of Mechanical Engineers. Over thirty years ago, when he was President of the Liverpool Engineering Society, he had given a lecture on the future of the air, so that his interest in aeronautics dated back a long way. The paper he was to read on the variable pitch airscrew, which he and Mr. Beacham had developed, was of great importance, in view of the interest in variable pitch gears during the last few years, and, in fact, for many years past. The Society was to be congratulated on the fact that a man of Dr. Hele-Shaw's eminence had gone to so much trouble in preparing a paper and the many diagrams and models for the purpose of illustrating it.

Dr. HELE-SHAW, before presenting the paper, paid a tribute to Mr. Beacham, with whom, he said, he was very proud to be associated in the development of the variable pitch airscrew.

THE VARIABLE PITCH AIRSCREW

WITH A DESCRIPTION OF A NEW SYSTEM OF HYDRAULIC CONTROL

BY H. S. HELE-SHAW, D.SC., F.R.S., AND T. E. BEACHAM, B.SC.

It has long been recognised that a fixed airscrew cannot give the best results under all flying conditions, and that its design, therefore, has to be a compromise. Under one set of conditions its efficiency may be the maximum obtainable, but under every other condition its efficiency certainly must be less than that of a propeller designed especially to suit that condition.

The subject, therefore, of variable airscrews has exercised the minds of aeronautical engineers ever since the underlying principles of the airscrew were clearly understood, and the records of the Patent Office show many attempts to evolve mechanisms to this end.

These include devices to vary the diameter and surface of the blades as well as to alter their pitch. This paper, however, only deals with variation of

pitch as the mechanical difficulties in the way of varying any of the other physical proportions of the airscrew are undoubtedly very great. It must be realised, however, that by the variation of pitch alone only part of the possible theoretical increase in efficiency can be realised.

Advantages of Variable Pitch Airscrew

For aircraft operating with engines not fitted with a supercharger, the chief advantage of the variable pitch airscrew would appear to be in greater efficiency at climbing speeds, as by reducing the pitch the drop in engine revolutions and consequent loss of power which occurs with a fixed pitch propeller is thereby avoided.

The variable pitch airscrew also prevents the loss of engine power due to the fall in speed which occurs at high altitudes.

With supercharged engines, however, the possibility of varying the pitch to suit different altitudes becomes a matter of prime importance because the power absorbed by a fixed pitch propeller is approximately proportional to the air density, whereas the supercharged engine should maintain something approaching constant horse-power up to a predetermined height. With a normal fixed propeller therefore it would be impossible to make use of the full power of the supercharged engine at any great height without excessive revolutions. This difficulty of course can be overcome by using a fixed propeller of greater pitch, but only at a great sacrifice of efficiency when flying at lower altitudes. The point is made clearer by the propeller efficiency curves in Figs. 1 and 2. Fig. 1 shows two efficiency curves for similar variable pitch and fixed propellers which have been taken from two published diagrams* and superimposed for purposes of comparison. The overall efficiency in the diagram is the practical

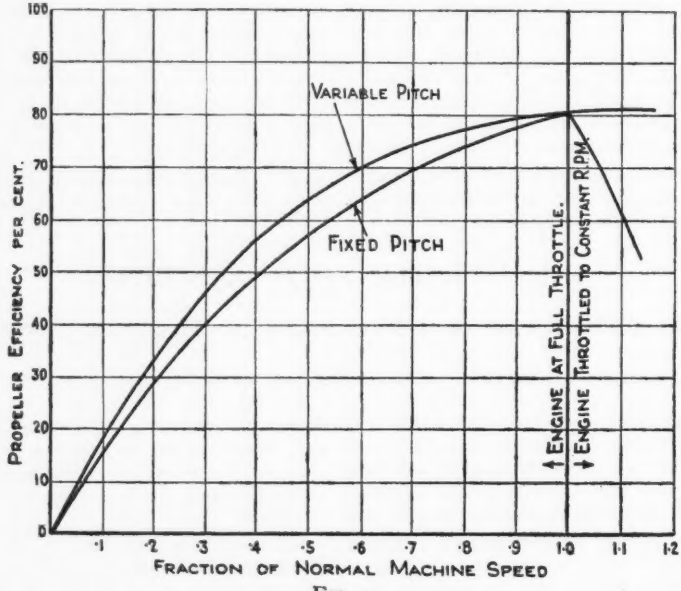


FIG. 1.

* "The Design of Screw Propellers for Aircraft," by H. C. Watts, pp. 149, 293.

efficiency of the propeller or the ratio of its thrust horse-power to the maximum b.h.p. of the engine at normal maximum revolutions. It will be noted that the fixed airscrew is such as to reach the efficiency of the variable pitch airscrew at the normal flying speed. At reduced speeds the variable pitch airscrew shows a considerable gain in efficiency. At speeds in excess of normal speed it is assumed that the engine is throttled to normal revolutions and it will be seen that the efficiency of the fixed pitch airscrew drops off very rapidly as it is no longer able to absorb the full engine power, whereas with the variable pitch screw the efficiency is fully maintained.

Fig. 2 shows the same variable pitch propeller curve compared with the curve for a fixed propeller of approximately 20 per cent. greater pitch, capable of absorbing a greater proportion of the supercharged engine power at high altitudes, with a consequent improvement in performance at these altitudes. A comparison between Figs. 1 and 2 shows, however, that this must be accompanied by a drop in efficiency at the lower altitudes and that the difference between the variable pitch and fixed pitch propellers becomes much more marked under these conditions.

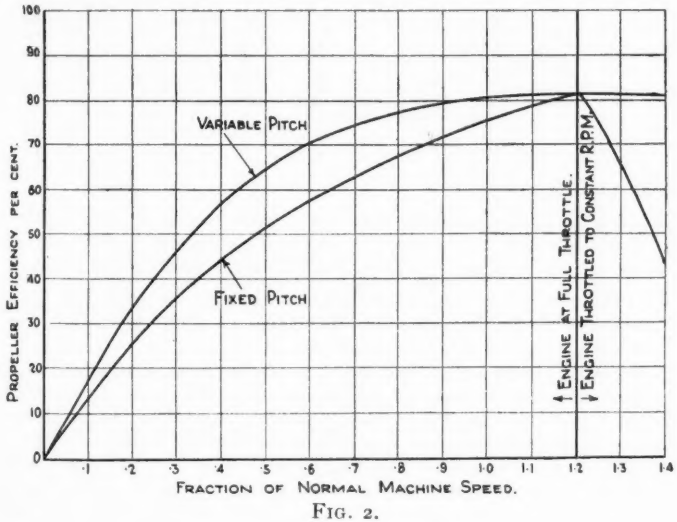


FIG. 2.

An example of the probable increase in climbing efficiency, due to the use of a variable pitch airscrew, has been worked out and published by Mr. C. C. Walker, F.R.Ae.S.* Fig. 3 has been reproduced from Mr. Walker's article and shows in a graphic manner his estimate of the possible increase in climbing efficiency by the use of a variable pitch airscrew, in this case with a non-supercharged engine, for the particular conditions specified in his article.

Apart from a direct increase in efficiency the variable pitch airscrew may have a considerable indirect effect on efficiency by reducing petrol consumption at cruising speed. With a fixed pitch airscrew the speed of the aircraft can only be reduced by throttling the engine. This reduces the compression pressure and the thermal efficiency of the engine, whereas with a variable pitch airscrew the speed of the aeroplane can be reduced by increasing the pitch and reducing the engine speed at something approaching full throttle.

* "Climbing Efficiency of Aircraft," *Flight*, January 27th, 1927.

A further possible advantage of the variable pitch propeller was pointed out by Major Mayo at a previous meeting of this Society,* and that is the possibility by the use of a variable pitch airscrew and geared engines of a twin-engined machine being able to continue flying with one engine completely out of action.

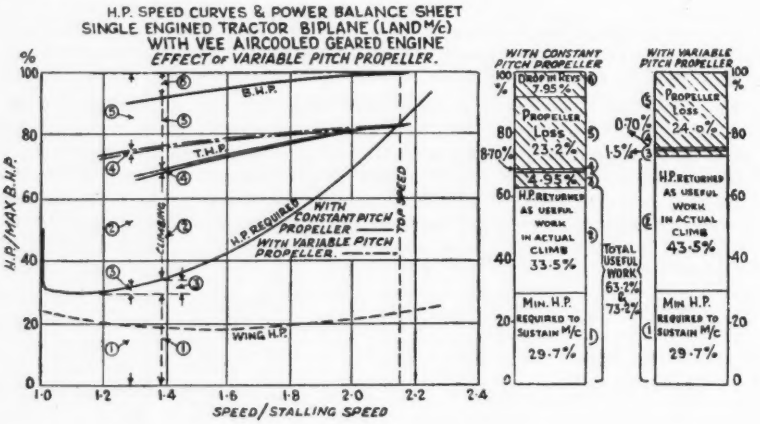

H.P. SPEED CURVES & POWER BALANCE SHEET
SINGLE ENGINED TRACTOR BIPLANE (LAND M/c)
WITH VEE AIRCOOLED GEARED ENGINE
EFFECT OF VARIABLE PITCH PROPELLER.
H.P./MAX B.H.P.
B.H.P.
T.H.P.
H.P. REQUIRED WITH CONSTANT PITCH PROPELLER
WITH VARIABLE PITCH PROPELLER
WING H.P.
CLIMBING
TOP SPEED
SPEED/STALLING SPEED
WITH CONSTANT PITCH PROPELLER
DROP IN REVS 7.95%
PROPELLER LOSS 23.2%
4.95%
H.P. RETURNED AS USEFUL WORK IN ACTUAL CLIMB 33.5%
MIN. H.P. REQUIRED TO SUSTAIN M/c 29.7%
TOTAL USEFUL WORK 63.2% & 73.4%
WITH VARIABLE PITCH PROPELLER
0.70%
1.5%
PROPELLER LOSS 24.0%
H.P. RETURNED AS USEFUL WORK IN ACTUAL CLIMB 43.5%
MIN. H.P. REQUIRED TO SUSTAIN M/c 29.7%

FIG. 3.

Mechanical Design

Having briefly pointed out the theoretical advantages of being able to vary the pitch of an airscrew, we naturally proceed to consider what progress has been made in the solution of this admittedly difficult mechanical problem.

In the first place it must be remembered that the problem of the variable pitch screw is an old one, but up to quite recently attempts have only been made to make variable screws for ships' propellers.

It is interesting to find that more than a century ago, in the earlier attempts to apply a screw for the purposes of propulsion, a suggestion was made of having a variable pitch and, as a matter of fact, a patent was taken out in 1816 by John Millington in which he proposes to use "two vanes with the plane of their motion from 45 deg. to any greater or less angle, according to the speed with which they are moved or the velocity which I wish to communicate to the vessel." It is safe to say that this idea never was practically applied even for ships, and that when many years later variable pitch screws were fitted by Maudslay in 1853 to H.M.S. "Aurora," and afterwards to many other ships, this was not for the purpose of improving propulsive effect but simply in order to feather the screws when out of action in order to avoid resistance to the motion of a ship under sail. Any knowledge gained with ships' screws of variable pitch is thus of little practical use in designing variable pitch airscrews. Quite apart from the fact that the fluids air and water have totally different physical effect on the material of which propellers are constructed, the whole dynamical problem of a screw propeller revolving in an incompressible fluid is fundamentally different from that of an airscrew which revolves in a compressible medium. To take one point only, the question of centrifugal force which is in most cases negligible in the well balanced screws of a ship becomes a very serious proposition in the design and construction of an airscrew. On the other hand, centrifugal forces on the blades of the airscrew, while involving careful design, have a stabilising

* Preceding Volume.

effect, which is of advantage, as otherwise the small degree of slackness necessary to enable the blades to turn freely in the airscrew hub might cause vibrations or flutter in the comparatively fragile structure of the propeller blade. The mechanisms which have been put forward of late years for varying the pitch of an airscrew appear to fall into three classes.

(1) *Manually Operated Gears.*—In these the pilot turns the blades of the airscrew through gearing by means of a hand wheel or its equivalent in the cockpit. The pilot has thus two tasks, viz., the determination of the right pitch setting and the physical exertion necessary to overcome the aerodynamic forces on the blades and the friction of the mechanism.

(2) *Power operated Gears,* where the pitch is controlled by hand. In many schemes this method of operation is effected by means of frictional contact, two trains of gearing being provided, one for increasing the pitch and one for diminishing the pitch. Each train of gearing is housed in the hub of the propeller and operated from a friction wheel or brake drum which rotates with the engine shaft and does not normally rotate relatively to the hub. The pilot can bring either train of gearing into operation. He does this in the case of the friction wheel by bringing a fixed wheel into contact with it, but in the case of the brake drum the result is obtained by bringing a fixed brake into contact with the rotating drum. In either case frictional contact sets in motion one or other of the two-wheel trains so as to vary the pitch. Again, the pilot has, in addition to his other duties, to consider the necessary amount of pitch variation though relieved from any physical exertion.

(3) *Power Operated Gears in which a Governor Adjusts the Pitch.*—The governor weight or weights may act directly through a spring to control the pitch of the blades or it may act through some form of servo motor. Both electric and hydraulic methods have been suggested for providing the necessary power so that a mere pilot governor is sufficient to vary the pitch of the blades.

The Authors believe that the methods falling under the third class, *i.e.*, automatically governed, present the ideal solution of the problem.

The operation of a governor relieves the pilot of an aeroplane from the duty of constant attention in connection with the adjustment of the pitch. For an airship, where propellers would be required to run for long periods at one pitch setting and where an adequate crew are available, a variable pitch gear requiring hand-setting may be the best scheme. In an aeroplane, however, where in order to obtain the best results the pitch would require frequent adjustment and where other duties in operating the machine require the whole attention of the pilot, it would appear to be a most desirable thing for the pilot to be relieved of any unnecessary duty, while at the same time having power of adjustment if such is desirable.

Although it is only during the last few years that serious attempts have been made to produce variable pitch airscrews, a considerable number of patents have already been taken out, falling into one or other of the above classes. A description of most of these devices could only be obtained from reference to patent documents and in any case the description of what in many cases are complicated machinery would occupy far too much space to be included in the present paper. The Authors therefore propose to limit the descriptive matter in this paper to an actual airscrew of the hydraulically operated type, which is that with which their names are associated.

An order was given to the Authors by the Air Ministry for a hydraulic variable pitch airscrew to be fitted to a Condor engine, which was made by Messrs. A. Harper, Sons and Bean, Ltd., and which has gone successfully through various spinning tests, has been fitted to a Rolls-Royce engine on an aeroplane at Farnborough, and the Authors have been promised a statement of the results of the trials in the air, which are now being carried out.

The Gloster Aircraft Company have completed the spinning tests of an airscrew fitted to a Jupiter engine, and the result of tests in the air will shortly be published.

Following the first appreciation of their invention by the Technical Staff of the Air Ministry, the Authors were fortunate to secure the co-operation of the justly celebrated Gloster Aircraft Company in the further development of their invention, and that company has, at great expense, been occupied for the last 18 months in developing the hydraulic variable airscrew. A large number of designs for many of the chief types of aircraft engines have been prepared at Cheltenham by Mr. H. L. Milner, Wh.Sc., working under the direction of the Chief Engineer and Designer of the Gloster Works, Mr. H. P. Folland, F.R.Ae.S., M.B.E., M.I.Ae.E. The first design to be actually carried into practical effect is that for the Jupiter engine. The airscrew fitted with this has dural blades constructed under the method and by the special machinery of the Gloster Co.

The Authors take this opportunity of acknowledging their indebtedness to the Gloster Aircraft Co., who are the sole licensees and manufacturers of the new airscrew. To the enterprise of this Company in incurring large expenditure, both in matters of design and experiment, the successful progress of the invention is largely due.

Before giving an account of what is known as the Gloster Hele-Shaw Beacham Airscrew, it will be well to discuss the general problem of hydraulic operation.

The Hydraulic Operation of a Variable Pitch Airscrew

At first sight the operation of a variable pitch screw by hydraulic means would seem out of the question. Hydraulic machinery is usually associated with operations requiring enormous force, such as with hydraulic presses, riveting machines, swing bridges, dock gates, etc., whereas the fundamental problem of an aeroplane is reduction of weight to a minimum. This most important question of weight, however, happens to be one which hydraulic means are able to meet better than any other power, since the forces available hydraulically are greater in proportion to bulk and size than any other form of steady action.

This matter of obtaining by hydraulic means considerable force with very small weight is so important that the Authors have thought it worth while to prepare a special working model variable stroke pump as illustrating this matter.

While the pump is small, a dial of large size visible to all the audience shows how a variable stroke rotary pump of small diameter can give a pressure even of more than 1,000 lbs. per square inch. Much less pressure on a small ram has been found quite sufficient to operate the blades of a large " Condor " airscrew above referred to when running at its full speed.

Now imagine a small variable stroke pump, instead of merely operating a gauge, acting on a ram and so moving the blades of an airscrew as to change their pitch; and the control of the pump, instead of being effected by hand, being operated by a governor. This is the principle of the Authors' airscrew, which will be hereafter described.

There is obviously a minimum weight for the economical employment of a variable pitch airscrew. If it imposes serious additional burden on an aeroplane, then it must give advantages superior to those that could be obtained by retaining the old fixed propeller and utilising such increase of weight in increasing the engine power. The experimental propellers show conclusively that the weight of the governor and hydraulic gear can be reduced to a comparatively small item and that the bulk of the weight increase is due to the blades, the blade mountings and the hub. Metal blades appear to be necessary as there is at present no satisfactory method of using wooden blades in a variable pitch airscrew.

Metal blades are not only themselves heavier than wooden ones, but the large centrifugal forces involved must be sustained on ball races of substantial size in order to enable the blades to turn without undue friction. The diameter of the hub must be increased to house these ball races and also the hub made longer to accommodate the journal bearings which support the thrust of the blades. Special tests on the ball races and actual tests of the operation have shown where weight can be cut down, and the Authors have no doubt that the variable pitch airscrew, in production, will be of a weight such that there are no cases in which a substantial gain cannot be effected by its employment.

Another point which is of course of vital importance is the question of reliability. The Authors have been for very many years engaged on variable stroke pumps operating ships' steering gear, known as the Hele-Shaw Martineau gear. This gear, although at first regarded with scepticism, is now operating many hundreds of ships in different countries and is rapidly displacing steam steering gear. Considering the rudder of a ship is probably the most vital part, this in itself is sufficient proof that hydraulic operations can be regarded as absolutely trustworthy and dependable.

It may be said at once that the principle on which the variable airscrew operated is identical with that of the hydraulic steering gear, consisting of a variable stroke pump in conjunction with hydraulic rams, the pump being controlled by a floating link in such a way that the operation of a lever compels the rams to take up any required position.

In the case of the steering gear the lever is operated by a wheel by the helmsman; in the case of the airscrew the lever of the variable stroke pump is operated by a governor and causes the pitch of the airscrew to automatically set itself so as to control the speed of the engines. Thus, while the same principle of operation is exactly as the successful hydraulic steering gear, the control is made automatic and the speed of the engine automatically kept at its highest efficiency.

There is the third and most important matter which is naturally insisted upon by the Air Ministry, namely, provision for any possible failure of the hydraulic system, for instance, if, in a war war machine, the pipes were shot away.

This condition is not only possible but has been satisfactorily provided for in the airscrew which will now be described.

Summarising the foregoing remarks there are three vital conditions, as follows:—

(1) Light weight.
(2) Reliability.
(3) Provision against possible failure of parts.

The Authors believe that the foregoing three conditions can be satisfactorily complied with by the hydraulic method.

The Gloster Hele-Shaw Beacham Variable Pitch Airscrew

The pitch of the blades in the above airscrew is varied by means of a double acting hydraulic piston operated by oil pressure from a variable stroke pump driven by the engine. The stroke of the pump is in turn controlled by a governor, also driven by the engine, so that whatever the air conditions may be the pitch of the airscrew sets itself so as to keep the engine running at a constant predetermined speed.

The speed at which the governor operates can be altered by the pilot within certain limits by means of a small control lever; that is, the pilot has it in his power to speed up the engine and obtain extra power in an emergency, and also on the other hand to reduce his engine speed so that he may cruise at full

throttle—this, of course, being the condition for minimum petrol consumption per b.h.p. developed by the engine.

Fig. 4 shows how the airscrew blades are coupled up and moved, all details being described later.

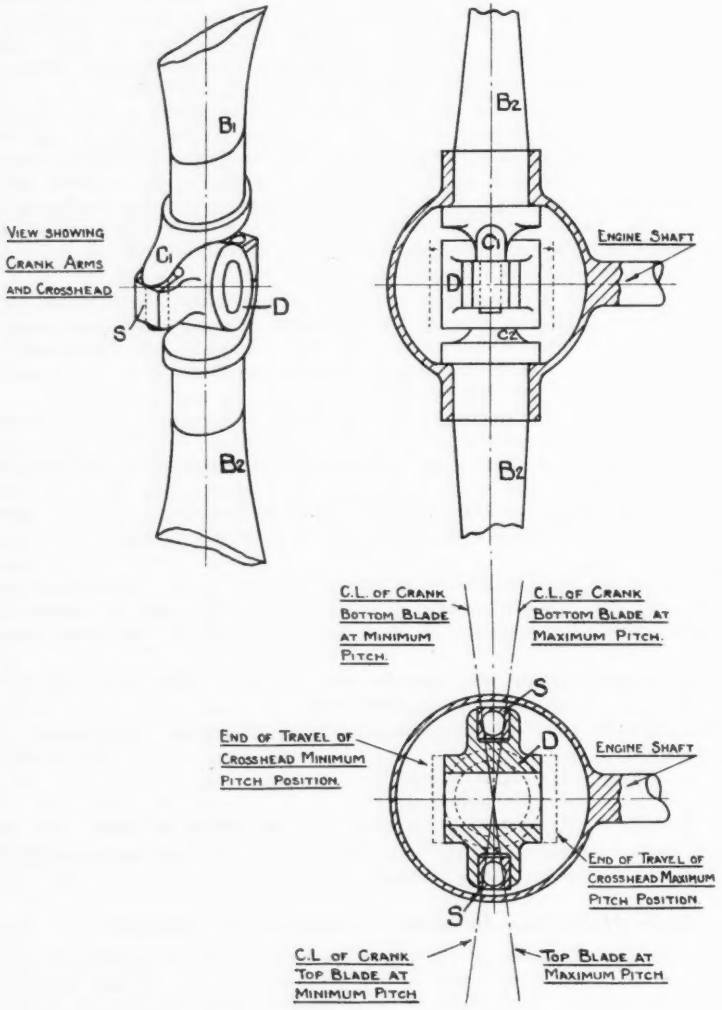


FIG. 4.

The two airscrew blades, B_1, B_2, are mounted in a special hub in which they are free to rotate independently about an axis at right angles to the shaft. On each blade is fastened a crank C_1, C_2, both cranks being operated from a common crosshead D, the crankpin being connected to the crosshead in each case by a small slider, free to slide a short distance in order to compensate for the angular

movement of the propeller blades. The hydraulic piston moves the crosshead to the right to increase the pitch and to the left to reduce it, the action being shown in the lower left hand diagram of Fig. 4.

Fig. 5 shows all the parts of the propeller and the hydraulic gear.

In this figure the mounting of the blades in the hub is shown in more detail. Each blade has two journal bearings and a ball race to sustain the centrifugal force on the blade without undue friction. The blades can be turned by crank arms C_1, C_2, both arms being connected in the manner already described to a crosshead D. The crosshead is secured by two bolts, L_1, L_2, to the hydraulic piston P which can slide axially in its cylinder. It will be seen that if oil pressure be admitted at the left side of the piston the crosshead will thereby be forced to slide to the right and vice-versa, thus rotating the blades by means of the crank arms and increasing or diminishing the pitch. The oil pressure is provided by the variable stroke pump which is connected through the two pipes shown to

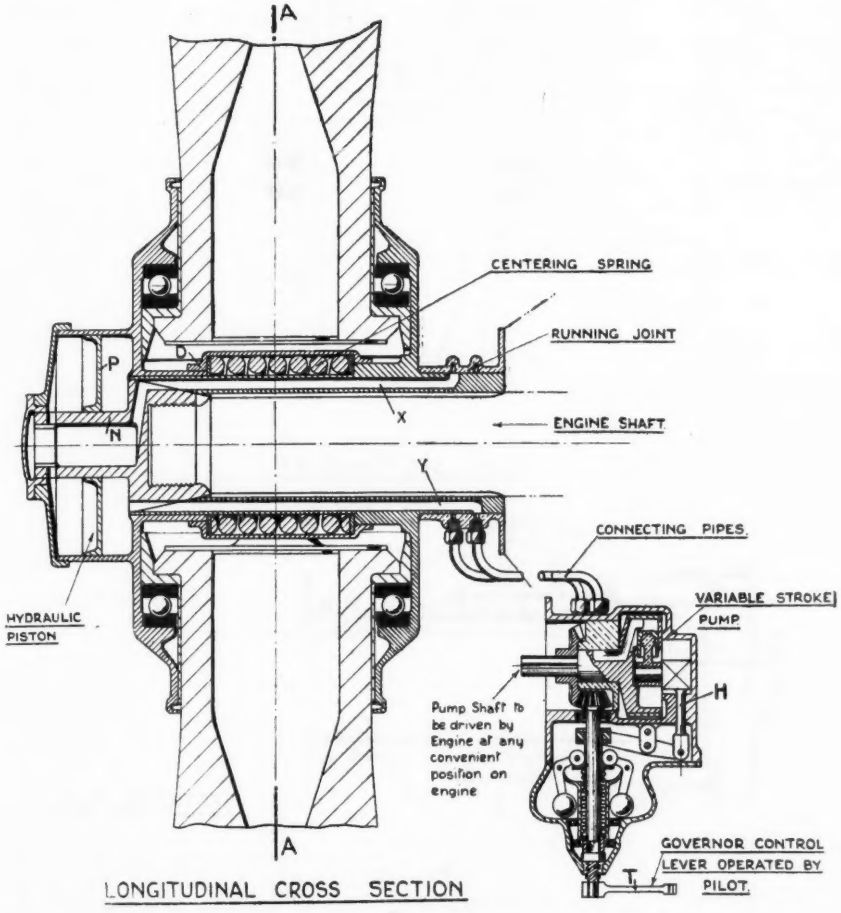
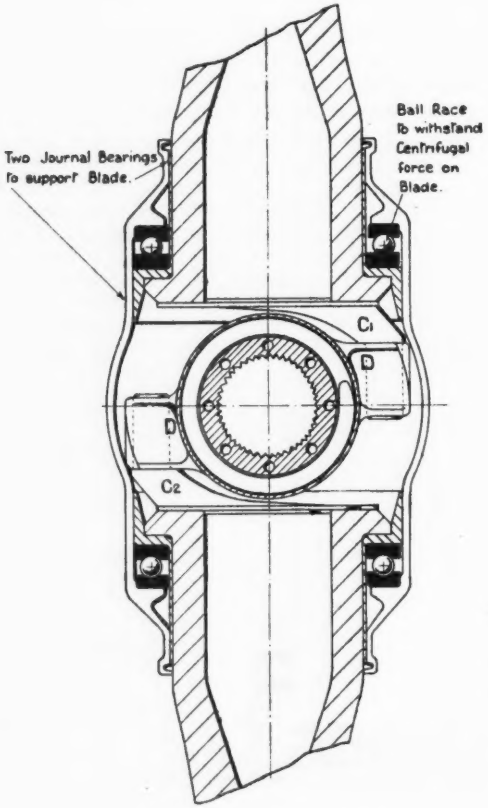
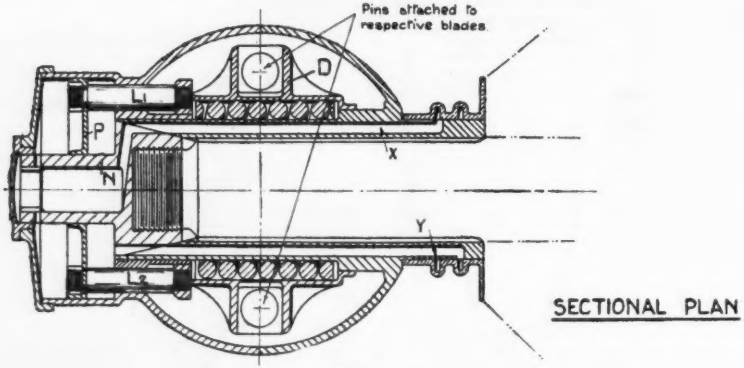


FIG. 5.



CROSS SECTION AT A.A



SECTIONAL PLAN

FIG. 5.

NOTE.—Drawings are diagrammatic only and must not be taken as representing actual construction of propeller.

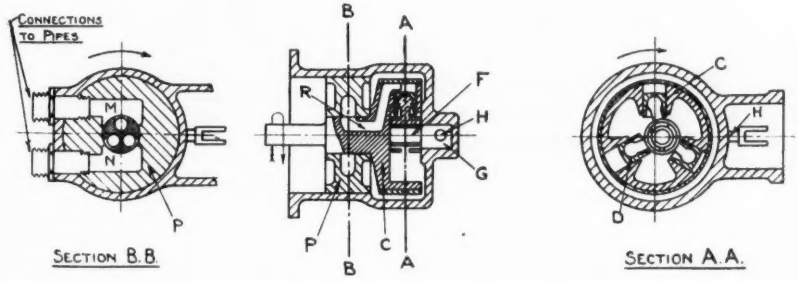
the running joint. The running joint is provided with two annular grooves, one being connected to each pipe. The grooves respectively communicate with the passages X and Y in the airscrew hub which lead to the left and right hand sides of the hydraulic piston. In the case of the passages X, these lead into the centre of the securing nut N and through small holes in this nut to the left hand side of the piston.

The pump has a variable throw crank operated by a small governor. The operation of the mechanism is such that at the correct speed the rod operating the change of stroke is in mid position and no oil circulates. If the engine speed falls the governor moves the stroke rod H and the pump forces pressure oil into one pipe causing the crosshead to move to the left and thus decreasing the pitch of the blades. If, on the other hand, the engine speed rises the governor will move the stroke rod the other way, the pump will force pressure into the other pipe and the crosshead will move right and increase the pitch.

The pilot control lever alters the force on the governor spring and consequently adjusts the speed at which the governor operates.

The spring which is shown inside the crosshead D is the centring spring and always tends to return the propeller to normal pitch. The smallest movement one way or the other from the normal position results in the spring exerting its full power to return the pitch to normal. The hydraulic pressure available is so powerful that it can easily overcome both the force on the propeller blades and the spring pressure, but in the event of the hydraulic system failing for any reason, the spring is then sufficiently powerful to return the propeller to normal pitch and hold it there, enabling the pilot to continue flying as if he had a fixed propeller.

Fig. 6 shows the action of the pump. The shaft of the pump drives the



DIAGRAMS ILLUSTRATING CONSTRUCTION OF PUMP

FIG. 6.

cylinder carrier C bored out to receive the three pistons D. In this carrier are also bored three sets of passages R, which lead from the respective cylinders to ports in the middle of the carrier which is formed at this portion into a cylindrical valve. This cylindrical valve rotates in the pipe connection P, which has two ports M and N. For one half a revolution each port R is in communication with M and for the other half with N. Each piston has a connecting rod connected to a single non-rotating crankpin F, the throw of which can be varied from nothing to a maximum in either direction by means of the stroke rod H. At the position shown in the section AA each piston is pumping during the top half of the revolution and sucking during the bottom half. In other words, the

pump is pumping out of port *M* into *N*. If now *H* be moved so that the crank is the other side of the centre of rotation the pump will suck out of *M* and pump into *N*.

In diagram Fig. 7 the pipes are shown. The two pipes of the pump are connected to the two sides of the hydraulic piston. If the engine speed is low the governor pulls out the stroke control lever *H*, the pump pumps out of port *N* into *M*, and thus moves the piston to the left which, as has been seen before, reduces the pitch of the propeller, thus lessening the resistance on the engine and enabling it to pick up speed. The action when the engine is above the normal speed is precisely the reverse. The governor pushes the pump stroke control lever *H* in, the pump pumps out of port *M* into *N* and thus moves the piston to the right. This increases the pitch and so brings the engine speed to the correct point again.

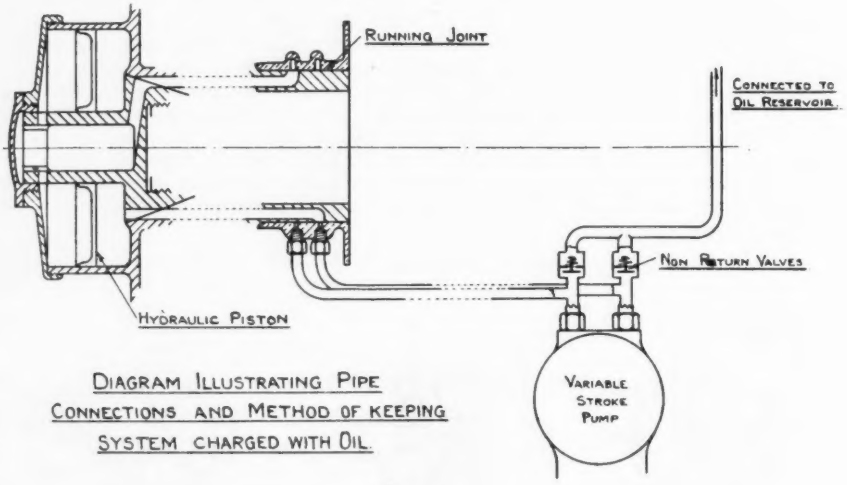


Diagram Illustrating Pipe Connections and Method of keeping System charged with Oil.

Fig. 7.

In order to keep the pipe system full under all conditions a small non-return valve is fitted between each pipe and a connection to the oil reservoir. In the case of the pipe under pressure the non-return valve closes. If leakage takes place anywhere a vacuum will tend to be created in the other pipe and the corresponding non-return valve will automatically open and oil will be drawn in from the reservoir to fill the void which would otherwise occur. This ensures that at all times the whole pipe system and hydraulic cylinder is absolutely full of oil and the crosshead is thereby held rigidly owing to the incompressibility of oil. There is consequently no backlash to start any fluttering action in the blades.

The next diagram, Fig. 8, shows one possible arrangement of the propeller on an engine. The governor pump unit is driven off the engine magneto drive and the pilot control lever connected by a rod to a small operating lever on the instrument board.

The figures illustrating the foregoing description must be regarded as purely diagrammatic as they have been especially prepared for the purpose of explaining the new airscrew.

Discussion

The Chairman, opening the discussion, said that many attempts had been made, even before the war, to produce a variable pitch airscrew, and at the commencement of the war this problem was discussed at nearly every meeting of the Advisory Committee on Aeronautics. It was always agreed that it was

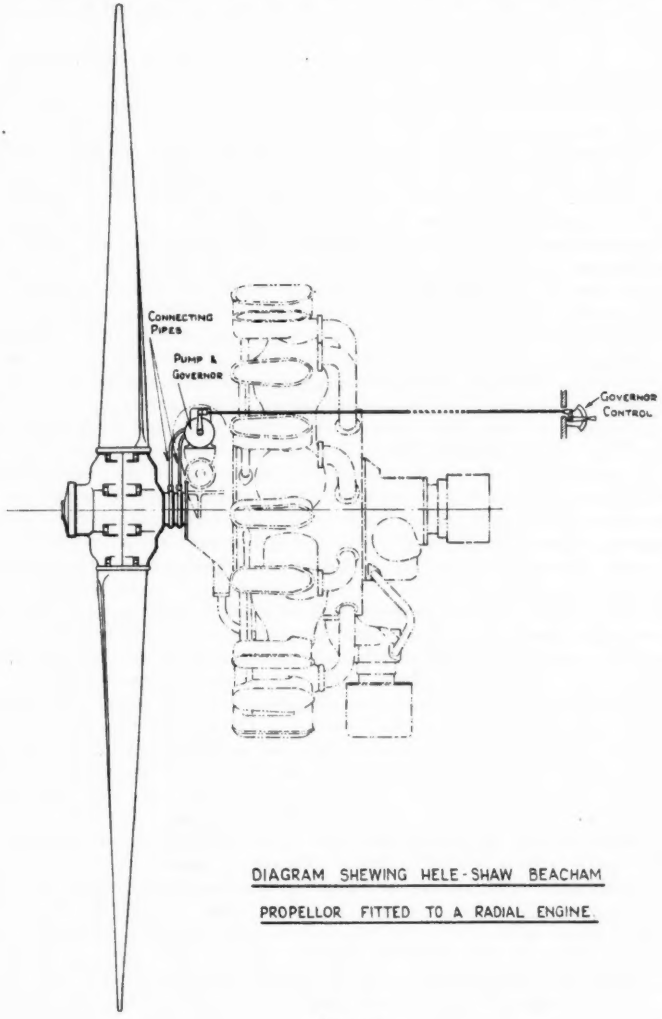


Fig. 8.

very desirable that something should be done to encourage the development of a variable pitch airscrew, and the result was the production of a variable pitch airscrew, about twelve years ago, at the Royal Aircraft Factory (as it was then known). That airscrew had operated quite successfully; it was fitted to a

BE2C, and had certainly demonstrated some of the advantages to be gained by the use of a variable pitch airscrew. He believed that both Mr. Lynam and Captain Forsyth were concerned with it. Very little further was done until after the war, when a number of people tried to produce variable pitch airscrews. Some of them had achieved no success at all, and some had achieved a certain measure of success, but he believed it was correct to say that the variable pitch gear developed by Dr. Hele-Shaw and Mr. Beacham had proved by far the most successful.

Mr. E. J. H. LYNAM (who is in charge of the Airscrew Dept. of the Royal Aircraft Establishment) said he agreed that the problem of the variable pitch airscrew was extraordinarily fascinating, but unfortunately there was a serious obstacle to its utilisation, viz., that of weight. If one took into account, as was essential, the weight of the airscrew, the proposition became much less attractive. In heavier-than-air craft, weight was of fundamental importance, and in the case of many variable pitch airscrews which had been constructed to date, was such as to seriously reduce if not practically annul the advantages to be obtained by varying the pitch of the blades. In lighter-than-air craft, weight was less important, and there were more advantages in varying pitch. Therefore, he considered that in the case of the airship a good case could be made for the use of the variable pitch airscrew, but he was certainly not convinced that a strong case could be made for its use on any heavier-than-air craft. Referring to the authors' diagrams Figs. 1 and 2, the advantage of the variable pitch airscrew over the fixed pitch airscrew is seen to be greater with the coarse pitch airscrew. With large pitch diameter ratio airscrews having large surface, the gain effected by varying the pitch of the blades was greater than with fine pitch small surface airscrews. With fine pitch airscrews, having small surface, the gain was almost certainly so small that it would be annulled by the effect of the increased weight of the mechanism of any variable pitch airscrew yet evolved. It would be appreciated, therefore, that the variable pitch airscrew offered greatest advantage on geared engines, where airscrews of large pitch diameter ratio and large surface would be used. In such cases there would be a comparatively large reduction in the rate of rotation of the airscrew during " get-away " and " climb " as compared with level flight, with consequent loss of engine horse-power. By varying the pitch of the blades, the maximum horse-power of the engines could be utilised in every condition of flight, although, unfortunately, not without reduction of efficiency. By reducing the blade pitch and increasing the speed of the airscrew, greater power was obtained from the engine at the lower air speeds, but the efficiency was reduced for two reasons. Owing to the decreased pitch diameter ratio, the efficiency was decreased, and secondly, owing to the greater h.p. absorbed without increase of diameter, the slipstream losses increased. One had, therefore, to ensure that the fall in airscrew efficiency did not annul the horse-power gained by increasing the speed of the engine. In addition, one had to take account of the increased weight. With supercharged engines, where the variable pitch airscrew had a better chance of improving the aircraft performance, conditions were, of course, much more complicated and very difficult to analyse theoretically. He believed, however, that it could be accepted that unless ground horse-power was maintained to great heights, certainly not less than about 20,000ft., it was doubtful whether the variable pitch airscrew would show any appreciable advantage when the weight had been taken into account. The case for the supercharged engine had been analysed by Mr. MacKinnon Wood, and Mr. Lynam referred the members of the Society to R. & M. 1112, which gave a theoretical analysis of the effect of supercharging, with and without use of the variable pitch airscrew. Whilst the variable pitch airscrew is required to take the full advantage of supercharging, this analysis shows that it is not of very great value if the time to reach operating heights is unimportant, or if good performance is required at medium heights and not at very great heights.

Summarising his remarks, he said that unless, by using a variable pitch airscrew —and taking the weight of that airscrew into account—one could obtain additional power from the engine at the rate of, say, 1 h.p. for 2lbs. added weight, it would be better to put the extra weight into the engine and use a fixed pitch airscrew. For heavier-than-air craft it was, therefore, very difficult to make a really strong case for fitting a variable pitch airscrew. In addition it will be appreciated that such devices must be costly and complicated, and therefore less reliable than the simple fixed pitch screw. It is true that the weight of the variable pitch airscrew is very much affected by the weight of the metal blades which have to be used in such airscrews. It is therefore necessary that metal blades appreciably lighter than those used to-day be produced. Until this has been achieved a really satisfactory variable pitch airscrew for service use could not be expected. Whilst admitting, therefore, that the weight of the blades had a considerable effect on the weight of the complete airscrew, he did not agree that that was the sole cause of the great weight of the variable pitch airscrews already constructed. The Gloster Hele-Shaw-Beacham airscrew for the Jupiter engine weighed about 180 lbs. The weight of a fixed pitch airscrew of the same size, with substantially the same blades—solid duralumin—was about 100 lbs., so that there was an 80 per cent. increase in weight due to the introduction of the mechanism for varying the pitch of the blades. He was not quite so sure of the weights of the Condor airscrews, but he believed this ratio was much the same. For light blades he believed we should be forced to hollow construction; he did not believe that any form of solid metal blade could ever be light enough to warrant consideration, except in the case of the very small screws used for racing craft. For practically all engines used in both civil and service aircraft, the weight of airscrews having solid duralumin blades was excessive. Even the hollow mild steel blades which were being produced by Messrs. Metal Propellers Ltd. were too heavy to enable the variable pitch airscrew to be used advantageously in many cases. To obtain lighter blades we must find methods of utilising higher grade materials than that at present used for the production of hollow steel blades, and secondly we must depart from the practice of attaching the blade rigidly to the centre. If the blades were hinged to the centre, they were relieved of considerable bending moment and could, therefore, be lighter. In this way the bending moment on the centre is reduced, as also is the centrifugal force due to the lighter blade, so that for two reasons the centre can be smaller and lighter. With the reduced bending smaller journal bearings could be used, and by reason of the lighter blade a smaller thrust bearing. A variable pitch airscrew of satisfactory weight was, therefore, hardly to be expected until we could produce light, hollow, hinged blades. Given such blades, he believed we should be able to produce an airscrew for engines such as the Jupiter or Jaguar for a weight of about 80 or 90 lbs. That, he considered, was the maximum weight which could be permitted, and he believed it might be possible to reduce it to 50 to 60 lbs. Discussing the particular automatically controlled airscrew which Dr. Hele-Shaw and Mr. Beacham had evolved, he said that automacity of operation introduced considerable complication and he could not believe that a device which contained so much mechanism could be considered so reliable as another which contained less. He was inclined to think that in very few types of aircraft to-day was an automatically operated variable pitch airscrew really required. He considered it was necessary in the single-seater fighting scout, which would probably have a supercharged engine, and where the pilot would require the very best performance from the machine at a time when he was least able to concentrate upon his controls, *i.e.*, when engaged in a fight. For large aeroplanes and seaplanes carrying heavy loads—civil aircraft and bombers—he believed it was agreed that there was no reason why one should not use a very much simpler manually operated gear. With such a gear the pilot would be able to set his airscrew to the best pitch for taking off, then adjust it to the best pitch for the climb, and having attained the

height at which he was to fly for long distances, adjust the pitch to that appropriate for most economical cruising. There were many other types of aircraft, particularly for Service use between the two classes he had mentioned, but it was very doubtful whether or no these really needed an automatically operated airscrew.

The CHAIRMAN asked Mr. Lynam if he could deal with the results of the trials of the Hele-Shaw-Beacham variable pitch airscrew for Condor engine, which were being conducted at R.A.E. under his supervision.

Mr. LYNAM said he would refer to that later.

With regard to hydraulic mechanism, he said he agreed with Dr. Hele-Shaw and Mr. Beacham that it had proved very reliable indeed, but that reliability was obtained with much larger machines than those which could be used on airscrews. He asked whether the authors had any experience of the reliability of small hydraulic machinery.

It was important that the pilot should have control over the governor, as mentioned in the paper. When taking off, it might be advantageous to utilise the maximum revolutions, whereas the aircraft would be cruised at much lower revolutions. To satisfy these requirements, the range needs to be greater than that provided on the Hele-Shaw-Beacham airscrew for Condor engine now undergoing trial. With this engine the maximum revolutions are 2,100 r.p.m., and it would probably be cruised at 1,600 r.p.m. Blade chatter, which had been a trouble in some very early variable pitch airscrew designs, was apt to be considered more serious than was really the case. He was not sure that this effect lessened as the centrifugal force of the blades increased. The main cause of blade chatter, in his opinion, was that with plain journal bearing at the root of the blade the clearance rapidly increased unsymmetrically. Backlash of the gear due to wear of the joints and pins had to be reduced by reducing the number of joints to the minimum, and using the largest possible rubbing surfaces. Dr. Hele-Shaw and Mr. Beacham had effected this in their design.

Dealing with the Chairman's request for information as to the results of the trials now being conducted with the Hele-Shaw-Beacham airscrew for Condor engine, he said he was not sure that he was privileged to give the information desired, because no official report had yet been forwarded to the Air Ministry. He could, however, endorse Dr. Hele-Shaw's statement, that it had been in flight for over thirty hours and that no breakdown whatever had occurred. As to its operation, those at the Royal Aircraft Establishment were not satisfied, but in the circumstances he could not give details.

Wing-Commander T. R. CAVE-BROWNE-CAVE agreed with the authors that, for airship purposes, a hand-operated variable pitch airscrew was probably the best. He also agreed with Mr. Lynam that for an airship one was justified in accepting a far greater weight than in a heavier-than-air craft in order to obtain the benefits of the variable pitch airscrew. He did not know what alteration of angle was possible with the mechanism the authors had described, but in the case of an airship one needed a much larger angle than that required in the case of an aeroplane. In an airship one wanted about 15° from neutral to astern, 15° from neutral to ahead, and 90° from neutral to the position of minimum drag. When some of the engines were stopped it was well worth while to turn the blades into the position of minimum drag. He doubted whether a gear of the type the authors had described could be made to give an angular range of 105°. The authors, it appeared, had not stated quite all the potential benefits of the variable pitch airscrew in an aeroplane. During the war attention had been drawn—largely by Colonel O'Gorman—to the desirability of being able to remove the drag of an airscrew when its engine had stopped. Many machines which had had their engines disabled a considerable distance on the enemy side of the line would have avoided landing in enemy country if they had been able to get rid of the drag of

their airscrews. That was admittedly rather a special advantage of the variable pitch airscrew, and one perhaps inapplicable even in future wars.

Again, if one engine of a twin-engined machine failed, and if the airscrew of the disabled engine could be fixed in the position of minimum drag, a great advantage would be gained in addition to the adjustment of the active airscrew to give optimum efficiency. These gains could only be realised with a variable pitch gear capable of the very large angular movement necessary in an airship, but which was not necessary under ordinary circumstances in an aeroplane.

In expressing admiration of the gear which the authors had described, he said it was exactly what we had learned by experience to expect from the source from which it came. It represented an extraordinarily beautiful and simple solution of a very complicated problem, and it had the very remarkable characteristic that it appeared to meet all the mechanical requirements. It was automatic and hand-controlled, and if it failed it would go back to the one and only position in which it would be safe.

Mr. CAPON said it was very difficult to be quite sure what improvement would be effected by the use of a variable pitch airscrew. The questions of the behaviour of the variable pitch airscrew at full throttle, when throttled, and on supercharging, were all separate questions. It was dangerous to quote unchecked figures, but he had attempted to evaluate the improvement effected in flying at full throttle by varying the pitch and could corroborate Mr. Lynam's statement that a definite improvement was effected if there were a large enough pitch-diameter ratio. He had obtained an improvement in the ratio of thrust power under climbing conditions at full throttle to engine power in level speed of 4 per cent. at a pitch-diameter ratio of 0.6; 9 per cent. at a ratio of 0.9; and 12 per cent. at a ratio of 1.2. The improvement at the higher-pitch diameter ratios was notable, and it was difficult to imagine that any reasonable increase of weight due to the variable pitch airscrew would annul that. He imagined that the increase of weight would be equivalent to 2 or 3 per cent. decrease in the airscrew efficiency. That, of course, would practically eliminate the advantage of the variable pitch airscrew as regards improvement of rate of climb for a pitch-diameter ratio of 0.6, but there was still a possibility of using such a device with advantage with a pitch-diameter ratio of 0.9 or thereabouts. In the case of a single-seater fighter there would be a particular advantage, because such machines, when fighting, were continually diving and rising again, and the variation of pitch if sufficiently rapid would give them a considerably increased climb. Such a machine, if fitted with a variable pitch airscrew, would always rise considerably higher after a dive than would its opponent, if the latter were not fitted with a variable pitch airscrew. It did not appear that a case could be made out for the use of the variable pitch airscrew in the larger and slower machines, and especially for its use in multi-engined machines for the purpose of giving increased thrust in the remaining engines in the event of the failure of one engine, because in a machine with several engines it would be necessary to carry the weight of several variable pitch airscrews in order to obtain the advantage of one of them in the event of the breakdown of one engine. The use of an engine gear ratio permitting of higher values of the pitch-diameter ratio might modify this argument, however. With regard to the supercharger, it was necessary to go very thoroughly into the question as to what exactly one wanted in supercharging. Finally, he congratulated the authors not only on their interesting paper, but also upon having reached a stage of development in variable pitch airscrews which had to his knowledge never been reached before.

Wing-Commander HYNES expressed admiration of the authors' device as a mechanical invention, but intimated that he belonged to what might be called the "anti-V.P." school, except possibly in a few special applications. He had taken part in many long and heated discussions on the problem of variable pitch airscrews, particularly at Farnborough, and the views of those at Farnborough had

been very ably put by the R.A.E. representatives. The problem of the variable pitch airscrew was a sort of carrot that had been in front of designers for many years. Whether it had arisen from intensive contemplation of the sort of curves shown by the authors he did not know, but those curves were definitely misleading. Theoretically they were correct, but they took cognisance only of the screw as a screw. The thing that mattered, from the aircraft point of view, was the maximum thrust horse-power of a power plant of a given weight, and if one is to make a true comparison between an engine with a variable pitch airscrew and an engine with a fixed pitch airscrew a weight correction must be made. If that correction were made, the power curve for the normal engine should be displaced upwards. The appearance of the diagrams would then be rather less in favour of the variable pitch airscrew; the normal fixed pitch airscrew would have advantages at the top and bottom ends of the curves, and in the centre would approach very closely the variable pitch airscrew. On the basis of the thrust horse-power per lb. of power plant under the various conditions, the advantages of the variable pitch airscrew were, to say the least, slight. Then one had to consider, in the case of the variable pitch airscrew, its very greatly increased cost, increased maintenance charges and the increased chances of breakdown—for it stood to reason that the more parts that were fitted the greater was the risk of breakdown—and taking these into account the case for the variable pitch airscrew became a very difficult one to support.

Colonel FELL pointed out that the application of the variable pitch airscrew to the super compression engine fitted to aircraft used for long-range work was very important. With the super compression engine there were limitations imposed by the fuel. One worked just on the detonation point, and in order to keep the detonation point reasonable one worked up to the maximum speed as much as possible. One was forced partly to throttle the engine on the ground, which meant that the power when taking off was very seriously reduced owing to the low r.p.m. available with a propeller designed to be suitable for operation at altitude. If the variable pitch propeller could be used in connection with such an engine, it seemed to him that that difficulty would be overcome. The variable pitch screw was probably like so many other devices, in that it would have certain applications but not universal adaptability, but it did appear that there was a very definite case in its favour in connection with the super compression engine.

Mr. H. MILNER: Mr. Lynam has presented a case for the fixed pitch propeller which is open to criticism, and in support of his point of view quotes figures for the weight of the V.P. propeller which do not fairly represent the true state of affairs.

It can be demonstrated that the weight of the automatic V.P. propeller can be reduced to well below the economic limit and also below that of a manually operated one working under similar conditions. At the same time he ignores the accepted theoretical advantages to be gained by the use of a V.P. propeller. Surely an increase of 10 per cent. in thrust power is not negligible.

Competent authorities admit that 6 per cent. increase of thrust power can be obtained at climbing speed by means of a variable pitch propeller of this type, and if one can increase the power output by 6 per cent. the power available for climb will be increased by at least 10 per cent. due to the fact that climb depends on the difference between power available and power required.

In the limiting case where a machine is so heavily loaded that it can only just take off, an extra 10 per cent. of excess power will enormously increase the margin of safety and certainly warrant the extra weight of the V.P. propeller. The V.P. propeller has a further advantage over the fixed type in virtue of the extra static thrust, which may be in the region of 17 per cent., thus correspondingly shortening the run to take off.

According to Mr. Lynam, automatic control has a strictly limited use because of the extra complication, but I would remind him that the mechanism involved works under ideal conditions of lubrication, is small and compact, yet robust and cannot be compared with the delicate mechanism of, say, a magneto which operates under more arduous conditions and yet is considered reliable. In any case the undoubted advantages far outweigh any extra complication due to the introduction of this feature.

The chief advantage is that automaticity makes no demand on the pilot's attention. On the other hand a manually operated gear entails a cumbersome hand-wheel or lever in the cockpit within reach of the pilot, and in a modern aircraft it would be difficult to find space in which to fit this control.

The above considerations apply to a normal engine. With a supercharged engine even Mr. Lynam admits that the " V.P. airscrew has a very much greater chance of improving performance," and it is generally agreed that a V.P. propeller is indispensable if full advantage is to be taken of supercharging.

Regarding Mr. Lynam's remarks on the Condor trials in which he suggests those at the R.A.E. are not satisfied with the operation, it is unfortunate that he could not make a more definite statement. As far as I am aware the only objection raised concerns the rate of change of pitch which Mr. Lynam considers too low. I need only say that the rate of operation is exactly as intended and in accordance with the requirements of the Air Ministry at the time of designing.

Mr. BURROUGHES said that the question of the value of a variable pitch gear in aiding the take-off might well be elaborated. In the taking off of a fairly heavily loaded aeroplane from a heavy aerodrome, or a seaplane from a rough sea, it should be of very definite value.

Referring to Mr. Lynam's criticisms, he pointed out that their value depended entirely upon what the weight of the variable pitch gear might be. In the new designs the weight had been cut down to a very great extent as compared with the weight of the gear now under test at Farnborough. Furthermore, it was now clear that considerable additional reductions in weight could be effected and the usefulness of the gear would be correspondingly increased.

Mr. W. O. MANNING, referring to the mechanism of the gear, said that some years ago, when he was experimenting with a small hydraulic mechanism—not in connection with a variable pitch airscrew, but of a similar type—he had experienced great difficulty due to the air getting into the small pump and preventing the pump working. So great was the difficulty that he had had to adopt an entirely different method, by means of which any air that entered was ejected practically at once. He would like to know whether this difficulty had been experienced with the authors' gear, and if so, how it had been got over. With regard to cost, he asked how the cost of the variable pitch airscrew compared with that of the ordinary propeller. Weight was obviously of very considerable importance, and no definite conclusion as to the advantages of a device of this type could be formed until accurate information as to weight was available. Referring to the drawings exhibited by the authors, he said he assumed they were not working drawings, as it seemed that the thrust race could not be got in. He assumed that there must be a loose sleeve attached to the propeller blade in place of the one shown. Again, nothing was shown of the methods of lubricating the various parts of the mechanism, and he suggested that some method of doing this should be incorporated.

Mr. BRAMSON said that throughout the discussion there had been a wave of undue pessimism, based on the supposition that the results so far obtained with the variable pitch airscrew were the best that the authors would ever obtain. That he considered to be unfair. At the present time a good deal of trouble, expense and weight was regarded as acceptable in order to provide a machine with a supercharger, but what point was there in having a supercharger which was intended to keep the horse-power of the engine reasonably constant at high

altitudes, and then, when the machine had reached those high altitudes, having to throttle down because the engine revolutions were higher than the engine would stand? It seemed to him to be absolutely essential, when a supercharger was used, to have ultimately a variable pitch propeller to absorb the power which one had taken a great deal of trouble to get. No doubt the "anti-school" would reply that if a propeller were designed to meet the conditions at high altitudes one did not need a variable pitch propeller. A propeller designed to meet the conditions at high altitudes, however, would be exceedingly inefficient at low altitudes, and it was surely essential that Service machines which were required to work at high altitudes should have high efficiency during the climb. With regard to the suggestion that the lightening of the variable pitch airscrew might be effected by hingeing the blades, he said that that would introduce a slight complication. He asked the authors' opinion as to whether some degree of lightening could not be effected merely by inclining the blades slightly forward, roughly in the direction of the resultant between the centrifugal forces acting on the blades and the thrust forces under ordinary working conditions. An interesting possibility in connection with the variable pitch airscrew was its use as a brake when landing in small spaces, and also for destroying temporarily the high L/D ratio of a machine when it was desired to descend into a small space over a high obstacle. Various attempts had been made to provide air brakes as well as wheel brakes for aeroplanes. If, when gliding into a small aerodrome, with the engine throttled down, one could reverse the pitch of the blades, and then, immediately on touching the ground, one could open the throttle a little, one could provide a good braking action on the machine and there would be no tendency to turn over, as there was when brakes were applied to the wheels.

Captain BOOTHBY said that in 1912 he was in command of an airship fitted with variable pitch propellers fitted with hinged blades—that airship had probably flown more than any other craft with such propellers—but he had disliked them because the blades, although made of steel, were only of the thickness of ordinary brown paper, and there was a liability to tear, and one subsequently did so. He had asked that those propellers should be removed and replaced by ordinary wooden ones—not because he did not like the principle of variable pitch propellers, but because he did not consider those particular specimens to be safe. In his view the variable pitch propeller would become an essential in airships. Large airships must have a reverse. In the past they had a gear-box, which was a nuisance, and if one studied the history of airships one would find that most engine failures were really gear-box failures.

He believed that when the rigid airships now building began to operate in tropical climates it would be found that swivelling propellers were essential to give adequate control, and save fuel and gas, in bumpy weather. A good variable pitch propeller would simplify the application of swivelling propellers to any airship, as it was only necessary to move the propeller through 180° to obtain the up, down, ahead or astern drive instead of having to move it through 360° as was necessary with a fixed pitch propeller; while the advantage of being able to vary the pitch according to the number of engines in use was always present.

Dr. H. C. WATTS said he would have liked to have disagreed thoroughly with Mr. Lynam, but unfortunately he was afraid he was in entire agreement with Mr. Lynam on most of the points the latter had raised. The main reason why the advent of the variable pitch propeller had been delayed so long was the feeling, amongst those who had investigated the matter, that its value was not commensurate with the extra weight and the complications which its application would involve. At least, that remark certainly applied to the ordinary single-engined machine fitted with a non-supercharged engine. Since the authors had done him the honour of exhibiting diagrams from one of his own publications, he ought to point out that the gains which were shown to be obtained by the use of the variable pitch propeller were based on the assumption that not only the

pitch but also all the linear dimensions had been varied, *i.e.*, that for every condition of flight one had the ideal propeller. The actual gain obtained by variation of pitch alone was something like a half or a third of that shown on the diagrams. A second reason for the delay in the application of the variable pitch propeller was the realisation that we must have a metal blade, and the application of the propeller must be delayed until we could produce a metal blade satisfactorily. The problem of producing a metal blade was now approaching very closely a satisfactory conclusion, but it was extremely difficult to lighten the blade further, and until we could get the blade very much lighter the variable pitch propeller would be very much handicapped.

Commenting on the authors' statement that the Jupiter engine screw was fitted with solid duralumin blades made by the Gloster Aircraft Company, he said he felt sure they would not object to his stating that the first screw, which was undergoing trial at Farnborough, was fitted with hollow steel blades made by Messrs. Propellers Ltd. He made that statement not purely for personal reasons, but because the value of the variable pitch propeller depended largely upon its weight, and there was very little doubt that an airscrew of the Condor size, with solid duralumin blades, would be extremely handicapped by reason of its weight, if its use were not altogether impossible. A third reason why the variable pitch propeller had been so long deferred was the necessity for finding a reasonable method of operation. There had been no insuperable difficulty in designing an airscrew the blades of which could be adjusted during flight; the difficulty had been to conceive a method of operation which would not entail undue exertion upon the pilot. Whatever one's opinion might be of the variable pitch propeller, the authors had helped considerably in solving one of the biggest difficulties in the way of its design, and that was the difficulty of operation. Referring to Mr. Bramson's suggestion that the blades might be lightened by inclining them forwards or backwards, he said he believed it was correct to say that that was already done in many cases. It was certainly done in the case of the hollow steel blades used on the Condor engine, and he suspected that it was done also in connection with the blades used on the Jupiter. Finally, he congratulated the authors upon the ingenuity of the automatic control they had put forward.

Major MAYO agreed with Mr. Bramson that the wave of pessimism with which the discussion had opened did not appear to be justified, because the variable pitch propeller seemed to have been judged before it had had a proper trial. He had noticed that the authors had been very discreet with regard to the question of weight. It was true they had mentioned that lightness was an essential requirement, but they had given no figures to show what had been achieved in the direction of reducing weight. Some of the criticisms made with regard to weight were very misleading. Mr. Lynam, for instance, had suggested that for every 2 lbs. extra weight of the propeller one ought to get 1 extra horse-power, and presumably he was basing this on the assumption that the weight of the power plant is as low as 2 lbs. per h.p. It would be interesting to know, however, what he included in the power plant. He (Major Mayo) knew of no power plant weighing as little as 2 lbs. per h.p., and if one took a comprehensive view of the average power plant one would find that the weight was very much higher. It seemed to him that when considering the merits of the variable pitch propeller one ought to include in the power plant the petrol that was carried, and that would make a very considerable difference in the balance sheet. After all, as he understood it, the total extra weight of propeller due to the variable pitch gear was something of the order of 80 or 90 lbs. for a 700 h.p. engine, and he understood that for an engine such as the Jupiter the amount of extra weight actually involved in the variable pitch mechanism was considerably less—something like 60 or 70 lbs. In a machine designed to fly for considerable distances it might well be that the saving in the amount of petrol to be carried would make up for the whole of the increased

weight of the variable pitch mechanism. If that were so, one would secure the whole of the advantages which the variable pitch propeller had to offer for nothing, so to speak, and that would be very important in the case of commercial machines. He was more interested in commercial than in military machines, and it seemed to him that the variable pitch propeller was particularly applicable to the commercial aeroplane and seaplane. It was now generally accepted that we must have geared engines for commercial work; he believed we should see very little more of large size commercial machines without geared engines, and, therefore, the conditions would be favourable for the application of the variable pitch propeller. Thus, there was a strong case for it to start with. Again, it might almost be said that the limiting factor in the design of commercial aircraft was the amount of load the machines could take off with. If the variable pitch propeller could give us an appreciable advantage in regard to take-off it might well be that we should be justified in carrying a slightly greater total weight on the machines. As to the objection that when two variable pitch propellers were carried on a twin-engined machine, the machine would be carrying the dead weight of one useless variable pitch gear if one engine broke down, he said that that would depend entirely upon the amount of the advantage to be gained by the use of the variable pitch propeller. If the advantage were such as was indicated by the author's figures, there was no doubt whatever that the propeller would amply justify itself. If we could get anything like the percentage increase of efficiency from the variable pitch propeller which had been mentioned, there was little doubt that the extra weight would be amply justified in the case of a twin-engined machine and still more in the case of a machine with more than two engines. We must wait and see what was the best that could be done in the direction of reducing weight and what were the actual advantages which the variable pitch propeller could offer. From the point of view of commercial aviation he would place the requirements in the variable pitch propeller in the following order of importance:—(1) reliability; (2) light weight; and (3) reasonable cost. With regard to reliability, it seemed that the authors had made an important step forward, and, from the little that had been heard as to the results obtained at Farnborough, it looked as though they would " deliver the goods " as far as reliability was concerned. He hoped the authors would be able to say a little more about weight. A mechanism of this sort was bound to add considerably to the cost of the propeller, but if the variable pitch propeller could be proved to be technically justified, then the additional capital cost would also be justified, because we could afford to pay a good deal for a comparatively small aerodynamic advantage.

(*Communicated*): In order to obtain a true valuation of the merits of a variable pitch propeller it is necessary to consider the weight of the aircraft as a whole and not merely the weight of the engine. The variable pitch propeller gives an increase in effective h.p. without increasing the amount of fuel consumed, whereas merely increasing the size and power of the engine means a corresponding increase in fuel consumption.

If this important point is taken into consideration it will be seen that the extra weight of the variable pitch propeller is really a matter of comparatively minor importance.

Mr. S. H. Evans (*Communicated*): I should like to draw attention to one particular sphere of application for the V.P. airscrew, which appears to have escaped mention during the discussion. Most of the critics have focussed their attention on the added weight of the pitch control mechanism as being a serious handicap to small fighters, rather neglecting large multi-engined aircraft where the weight account is not so important.

In pursuit of the desirable ideal of " safety first," it is generally conceded that the multi-engined machine is a necessity nowadays. It is unfortunate, however, that this ideal has been pursued in favour of the three-engined arrangement,

regardless of aerodynamic efficiency and power economy. It would seem that with the successful advent of the Hele-Shaw-Beacham V.P. airscrew, it will now pay designers of multi-engined aircraft to reconsider the merits of the twin-tandem four-engined machine, since it can be shown to have certain advantages over the former.

For instance, it is clear that the three-engined machine has some of the most undesirable features of both the single-tractor and the ordinary twin: thus the high slipstream drag at climbing angles due to the centre engine, plus the drag of outboard nacelles; moreover, the efficiency of the centre airscrew is reduced by the presence of the large body and possibly cylinder interference.

On the other hand, the chief drawback of the twin-tandem in the past has been the serious loss in thrust of the pusher screw when its tractor is out of action, a position which should be improved by the introduction of V.P. mechanism to the rear engines. Although one must not lose sight of the fact that the rear screw of a tandem combination is necessarily of lower efficiency than the leading one even under optimum conditions of working, the balance of advantages would still appear favourable to this arrangement. Slipstream drag over the large body would be non-existent and we might expect a cleaner nose and body design altogether, at least in civil aircraft. The turning moment with one engine cut out would be decreased for several reasons and there would be less vibration and noise in the cabin; also if the four engines were mounted direct on the bottom wing of a biplane they ought to be more accessible.

It is the writer's view that the authors of the paper have opened up a new lease of utility for the four-engined machine, since if this gear can be brought down to 50lb. per screw—and there is no reason to doubt this figure—then a very good case can be presented for its use in this field of design, the addition of 100lb. being a very small price to pay for its advantages on machines of 10,000-20,000lb. total weight. In any case, they are to be congratulated on the mechanical ingenuity of their solution of the problem.

Mr. FAGE (*Communicated*): The theoretical arguments advanced by Dr. Hele-Shaw and Mr. Beacham in favour of the variable pitch airscrew leave little room to doubt that if the operating mechanism can be made light and reliable, a variable pitch airscrew may possess important aerodynamic advantages. It does not follow, however, that it is always expedient to fit a variable pitch airscrew, since the character of the flight contemplated has to be taken into consideration. For example, on well-established air routes, the best cruising speed and altitude are known from experience, and since appreciable departures from schedule do not often occur, one would not expect the economy of running to be appreciably improved, if a variable pitch airscrew were used instead of a normal airscrew designed to run most efficiently at the known cruising speed and altitude on an engine of known characteristics. It appears to me that in this case the argument against a variable pitch airscrew is not a question of the additional weight and the possibility of a breakdown of the operating mechanism, but rather that a variable pitch airscrew is not needed because the conditions of the flight are definite. On the other hand, if the aeroplane has to cruise for long periods at an altitude and speed which cannot be predetermined, or if it has to perform extreme manœuvres (rapid climb, etc.), at an unknown height, then a variable pitch airscrew is needed for the best economy of flight and the most efficient performance. Naturally one would hesitate to fit a variable pitch airscrew until the reliability of the operating mechanism had been thoroughly proved; a point of view which appears to have received practical consideration by Dr. Hele-Shaw and Mr. Beacham.

Major D. H. KENNEDY (*Communicated*): I desire to support the President's appreciation of the pioneer work of Messrs. Hele-Shaw and Beacham.

I foresee a time, not far distant, when the commercial air liner will have engines equipped with variable pitch airscrews. They will be larger than the present types, will run more slowly and be much less noisy. The passengers

in the saloon will be able to talk in comfort, and the service will have become so popular as to be self-supporting. In the event of trouble on one of the engines it can be stopped and its propeller turned to a minimum resistance, while the propeller of the working engine is adjusted to take the increased load.

In the event of a forced landing in a small space the propeller of the working engine can be reversed for air braking.

Starting of engines will be facilitated by setting the propeller to zero pitch.

Mr. J. D. NORTH: I have read with interest the paper by Dr. Hele-Shaw and Mr. Beacham, and if the ingenious mechanism illustrated in their paper represents a satisfactory solution to the variable pitch airscrew problem, they will have made a valuable contribution to the progress of aeronautical engineering.

The improvement in performance to be expected from the use of a variable pitch airscrew has been well understood from the earliest days, and I think it is quite correct to say that questions of mechanical difficulty, weight and cost, are all that would stand in the way of the universal adoption of such an airscrew.

The possibility of using short period boosting, together with appropriate fuel, offers advantages which are nearly as great as those of the variable pitch airscrew in theory, and it will be interesting to watch this alternative line of development. It is understood that the airscrew as illustrated is of an experimental type, and that it is expected that development airscrews would be considerably lighter. It would be of great help in appreciating the paper, if some figures could be given indicating the weights which have been realised and which are expected to be attained. This information would enable the aeronautical engineer to form a better appreciation of the probability of the useful application of the device described in the paper.

Mr. C. C. WALKER (*Communicated*): Differences of opinion are sometimes heard as to the value of having the pitch of a propeller variable in the air. This probably arises from the fact that those who differ are not considering the same initial propeller conditions, and are, therefore, both right.

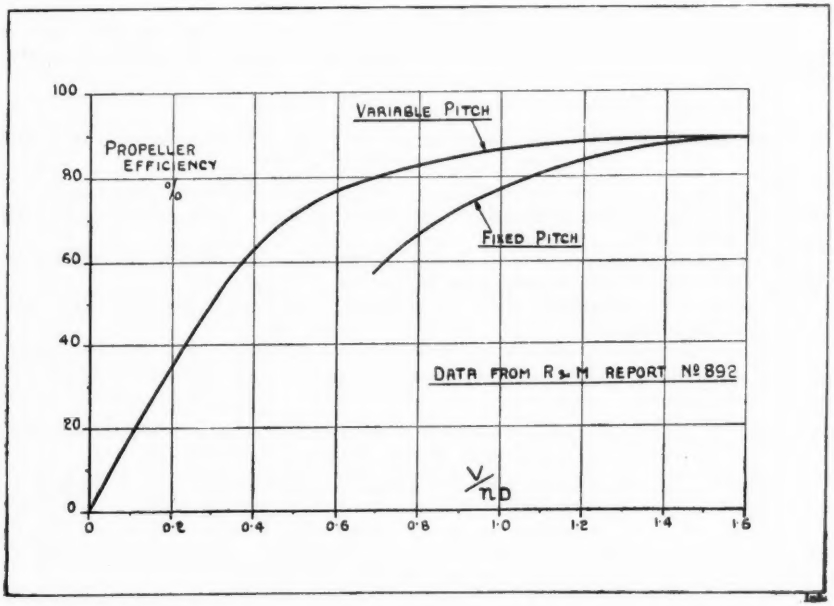
The application of variable pitch to a propeller absorbing 500 b.h.p. and turning at nearly 2,000 r.p.m. would have no beneficial effect whatever on an aeroplane having a speed range of say 2: 1. The most efficient propeller for climb would be that designed for speed and the loss of r.p.m. on the climb with this propeller would not be serious.

Happily the day of these intolerably bad conditions of " advance-per-revolution " seems to be coming to an end, owing to the introduction of more reasonable propeller speeds. The case for the variable pitch then becomes a strong one. In the zone of higher " advance-per-revolution " which is covered by the geared down propeller, a large range of forward speeds may be dealt with without any serious alteration of efficiency. To obtain this desirable state of affairs a variable pitch propeller is necessary, which has the additional advantage of allowing full r.p.m. on the climb. In an aeroplane of 2: 1 speed range, it should be possible never to go below 80 per cent. efficiency between climb and speed provided that the initial propeller conditions are satisfactory and the pitch may be varied in the air. This it will be admitted would be one of the greatest advances in sight at present for bombers or commercial machines, where the " take-off " is the limiting consideration. While I cannot pretend to have looked very thoroughly into the practical side of this problem which might involve difficulties connected with ground clearance or impracticably big and heavy propellers, I think it is obvious that a large gain in climbing horse-power is possible by the use of variable pitch.

There is also the case of the supercharged engine, which is a rather different one, and at the present time there does not seem such a pressing need for the device in this case, which may be partly looked after a compromise propeller.

While admitting that I am rather looking ahead in the matter of improvement in propeller conditions, I think that Figs. 1 and 2 in the paper hardly do

justice to the variable pitch possibilities, and would suggest that the attached figure represents what would be obtainable (always with the reservation about



practical difficulties) if the initial propeller conditions were made ideal. This does not take into account the increased r.p.m. obtainable on the climb. The total gain thrust h.p. resulting means that something like 3lbs./h.p. more could be taken off with, if the pitch were variable.

In judging the value of a device, the most favourable field for its operation is the one to look at, and I think that it is obvious that the bomber and the air liner with slow runing propellers show that theoretically, at least, the case for variable pitch cannot be disputed and is very strong indeed.

As regards weight, cost and complication—weight is about as important as in the case of the gear reduction. The geared Jupiter with propeller weighs about 200lbs. more than the ungeared and no one would think of selecting the ungeared for the class of aeroplane in question.

Cost and complication are important matters, but cost in purely commercial vehicles is a matter of how much additional revenue can be earned. In this and other cases, the variable pitch propeller is in competition with the installation of a more powerful engine.

There is no doubt that all smaller aircraft must be simple, straightforward and cheap, and the addition of another organ, a mechanism of some complexity, can probably not compete with the alternative of having rather more engine power in these cases.

The fact that 30 hours without trouble has been obtained on one of the first propellers made, is highly creditable and the future will be watched with very great interest.

It is difficult to see straight away whether automaticity is better than control by the pilot. I am inclined to think the latter is preferable in the cases considered above, and it can, undoubtedly, be easily thus arranged.

One hopes the new propeller will be tried out in the future in conditions where it is a real advantage. The addition of a more or less complex mechanism to the aeroplane seems to be the only weight on the wrong side of the scales. The case for it on paper is a strong one.

Mr. P. A. RALLI (*Communicated*): There appears to be no doubt that a variable pitch propeller can be beneficial to the performance of aeroplanes, given certain conditions.

Two classes of machines should be considered from this point of view.

I.—High-speed, heavily-loaded aircraft and/or with difficult take-off conditions (seaplanes and long-range aircraft).

Fixed pitch propellers in similar cases may be designed for speed, but the take-off will then suffer, especially if the speed range is such that the propeller stalls at low speeds.

It is practically impossible to design the propeller for take-off as the engine would have to be throttled over most of the speed range.

A compromise propeller is also unsatisfactory, although it may be the only fixed pitch alternative.

The advantages of variable pitch are very marked in such cases as these, and may amount to 10 per cent. on speed and 10 per cent. on take-off compared to a " compromise " propeller.

II.—Aircraft with limited speed range or with high-speed range but light loading, in which take-off is not in question.

In this case a fixed pitch propeller designed for speed, or with a slight bias towards climb, will give a perfectly satisfactory result for all practical purposes.

A variable pitch propeller could not appreciably improve climb and speed. It would have to exhibit unusual qualities of simplicity, reliability and cheapness to be considered worth fitting for its influence on take-off.

In conclusion it may be noted that the aircraft covered by (II.) form a very numerous and important class for which variable pitch is not at present an indispensable item.

As regards the machines in class (I.) it must also be assumed that the mechanism proposed is thoroughly reliable and satisfactory in operation.

These considerations may account for the strong divergence of opinion on the merits of variable pitch; exponents holding opposite views probably have in mind the two very different classes of machines referred to above.

The CHAIRMAN said he was very much impressed by the difference in the tone of this discussion as compared with most others. Usually, the discussions on aeronautical subjects were optimistic in tone, but that was hardly so in this case. He agreed, however, with the view already expressed by Major Mayo, that the wave of pessimism with which the discussion had opened was unnecessarily severe, for we could plead that the development of the variable pitch propeller was in its early stages, and that the weight of the gear to-day was no indication of what its weight would be when due encouragement had been given to its development and proper time had been taken in perfecting and improving the various designs. So far as the commercial aspect was concerned, little had been said as to the advantage of the variable pitch airscrew when taking off, particularly in the case of the flying boat, where it was desirable to obtain the maximum possible efficiency in order to get into the air without delay. He would have thought also that more stress would have been laid on the advantages of the variable pitch screw on fighting machines with supercharged engines. Again, he would have thought that the fact that the gear was automatic, and yet under the control of the pilot, constituted a very desirable feature. It was desirable that it should be under the control of the pilot, and its automaticity introduced another safety factor. The question of reversibility was an interesting one, and the development of the variable pitch airscrew in

that direction was a natural line of investigation. He appreciated that there were technical disadvantages, but the practical results were quite amazing, as he found when he tested such a gear ten years ago. Finally, the Chairman said that the aeronautical community was proud of the fact that an eminent man like Dr. Hele-Shaw and his associate, Mr. Beacham, should have come in from other walks of life to aeronautics in connection with a development which had been studied for many years, but which had never previously reached the stage to which they had now brought it.

Reply to Discussion

Mr. Beacham, replying to the discussion, said that most of the criticisms of the variable pitch propeller seemed to turn on the important question of its weight. The drawing that had been exhibited was not the exact drawing of the original propeller made for the Condor engine, which was now being tried out at Farnborough, but it was very close to it, and in designing that propeller the authors had had no idea whatever as to what forces were necessary to turn the blades; in consequence, they had allowed for greater forces than were really necessary. As a matter of fact, the pump and the whole hydraulic system was capable of withstanding a pressure of something like 800 or 1,000 lbs. per sq. inch, whereas the pressure in actual flight was only about 200 lbs. per sq. inch. That was a very interesting point, because on the spinning tower the pressures went up to 600 lbs. per sq. inch, and it looked as though the vibration from the engine destroyed almost all the friction in the mechanism. The force on the ram at 200 lbs. per sq. inch was very different from that at 1,000 lbs. per sq. inch and, based on the results obtained in practice, the design had been overhauled entirely. It had been found that the whole of the ram mechanism could be put inside the shell which surrounded the propeller. Other details had also been dealt with, and as a result the propeller, instead of weighing about 100 lbs. more than the ordinary screw, now weighed only about 50 lbs. more. Weight, after all, was a matter of detail, and the weight had been reduced as the result of the experience in practice.

Discussing Mr. Manning's statement that, when experimenting with a hydraulic system, he was troubled with air leaking into it, Mr. Beacham said that air, of course, was the natural enemy of all hydraulic systems, and the system with which Dr. Hele-Shaw and himself had been associated was specially designed to expel automatically any air that leaked into it. Any accidental leakage of air into it was expelled through the pump. The condition for successful working was that air must be expelled at a greater rate than that at which it could possibly leak in, so that if a machine had been standing for some time and a certain amount of air leaked into the system, that air would be expelled by the normal working of the machine within a few seconds after starting up, and while the machine was working the air could not possibly leak in again.

It would be noticed that there was no packing, absolute reliance being placed on the automatic exclusion of air. Replying to Wing Commander Cave-Browne-Cave's question as to the angular variation necessary in an airship screw, he said he did not know, without going closely into the matter, whether a variation of 105 deg. would be possible in this mechanism. For ship steering gear the maximum variation in use was about 45 deg. on each side of the centre line, *i.e.*, 90 deg. in all, but perhaps, by the use of a connecting rod instead of a slider, that 90 deg. could be increased to 105 deg.

Dr. Hele-Shaw, who also replied, said that when Mr. Beacham and himself had had the presumption to invent a new form of variable pitch airscrew they quite realised that they were attacking a problem which had already been the object of study by a great many minds, and very acute minds—many of them at Farnborough. Commenting upon the criticisms that had been made, he

said it was his experience that if everyone spoke well of a man and his invention they did so out of sheer good nature. They felt that the poor fellow had missed the bull's-eye, and that a little kindness would soften his failure. In a lecture he had delivered many years ago, before the Society of Arts in this very hall,* he had pointed out that the history of all progress was from simplicity to complexity, and not from complexity to simplicity, although many modern things were apparently simple. The outside case of an engine seemed to suggest that the engine was much more simple than one of thirty years ago, judging by the bonnet of a motor car of those early days, but it was not really more simple. Reference had been made during the discussion to the complexity of an automatic pitch mechanism; but any aircraft engineer might well contrast the Jupiter engine with the simple steam engine. Fifty years ago he was fourth engineer in a tramp steamer. The engines on that boat were of 99 h.p., and he believed the weight of the whole machinery with boilers was something over 100 tons—or more than one ton per h.p.—though that boat was one of the best ships of its kind at that time. And yet to-night Major Mayo had said that he knew of no aircraft machinery *of less than 7 lb. per h.p.* When he was Professor of Engineering at Liverpool University he had been presented with the first turbine which his old friend Sir Charles Parsons had put on to a ship for working the electric light. To-day a turbine of that weight would be almost sufficient to drive a large yacht. If there was one satisfactory feature of the discussion that evening it was the criticism of the weight of the variable pitch airscrew. The reason for its large weight was that every part was designed with a large factor of safety. To-day there was no factor of safety on the ordinary airscrew, but despite the terrible things that happened—and must happen—an enormous number of flights were made with perfect safety, and he considered that one was just as safe, under proper conditions, with no factor of safety at all (laughter). He welcomed the comments which had been made upon the invention which Mr. Beacham and himself had brought forward; they had not expected to be patted on the back for having done what Farnborough had not done, *i.e.*, for having produced an automatic airscrew which did all that was required of it. He hoped to see the excess weight of the variable pitch airscrew reduced by half, which indeed Mr. Milner had indicated would be the case with the next Condor machine to be made. It might be pointed out that they had occupied, in the development of this airscrew, about 1 per cent. of the time that had been occupied in bringing the aeroplane to its present stage. They had written the paper in order to find out from people who knew more about the subject than they did what were the weak points of their invention, and he believed, at any rate, they had heard what the weak points were (laughter). Finally, he expressed his thanks to the speakers for their criticisms.

At the conclusion of the discussion a hearty vote of thanks was accorded the authors, on the motion of the Chairman.

Reply to Correspondence

The authors consider, after a general review of the discussion, that they had every reason to be satisfied with the comments and criticisms which their paper had elicited. They believed that, as far as they were aware, this was the first occasion on which there had been a discussion before a scientific society of the general proposition as to the possible advantages to be obtained in securing variable pitch for an airscrew.

The authors have now heard the opinion of a number of men whose practical experience and technical knowledge of aircraft was of the highest order, and it is a matter of great significance that no one has denied the great importance of being able to obtain variation of the pitch of an airscrew if only the result

* Proceedings of The Society of Arts, 1885.

could be obtained without paying too high a price for it, either in weight or complexity of mechanism.

Mr. Lynam was responsible for the production of blades at Farnborough for the Service, and his actual words were " the obstacle in the way of the utilisation of the variable pitch airscrew was its weight, . . ." later on, " the weight of the variable pitch airscrew constructed so far had been so great as to practically annul, in very many cases, the advantages to be gained by varying the pitch of the blades." He quoted the Jupiter airscrew, which has now been constructed and passed through its bench test and is about to be put in actual flight, as being a weight of 180 lbs., an increase of 80 per cent. on the same airscrew without a variable pitch mechanism. He also referred to the Condor and believed that the ratio of increase, namely, 80 per cent., was about the same. This latter statement, however, was not correct as the increase of weight in the case of the Condor, as designed by the authors, was only 40 per cent. as compared with the Jupiter. Now as this matter of weight was really by far the most important question, and also the chief subject of criticisms, the authors hoped they would have an opportunity of bringing before the Aeronautical Society the facts which would soon be available of a subsequent design which already had reduced the increase of weight to half that above stated, *i.e.*, about 20 per cent. in the case of the Condor airscrew. Possibly if this opportunity is afforded them they will be able to refer the Aeronautical Society at the same time to developments in the construction of hollow blades for an airscrew which, together with the above improvement in design, will more than meet the challenge concerning weight which has figured so largely in the discussion on this paper. The matter of weight in almost every engineering proposition, and especially those of machinery in motion, is inevitably reduced with experience and the authors will therefore not take up further time on a subject about the future of which they had every confidence.

The next point, and practically the only other point of importance, was the question of the automatic method of pitch variation as compared with the manually operated mechanism. Now in the case of hydraulic machines there was no question that enormous and yet perfectly reliable forces could be obtained, and it was because the authors anticipated the very point being raised in the discussion that they had shown to the audience an example of a pump in operation capable of giving a pressure of more than 3,000 lbs. per sq. inch, the whole of this pump not being much larger than an ordinary watch. But as this might be regarded as a mere table experiment, it was satisfactory to be able to say that some of these pumps, exactly identical with the Condor pump, were actually in use for various purposes. One of these pumps employing a pressure of more than one ton on the inch was continuously operating a large testing machine at the London University; this pressure is ten times higher than that employed for operating the variable pitch airscrew of the Condor. This fact in itself will give some idea of the large working factor of safety which it was possible to obtain with the hydraulic system.

So much then for the question of reliability. As to simplicity the variable stroke pumps which the authors were employing for aircraft were really very simple appliances in themselves, and although on a small scale were similar in principle, as had already been intimated in their paper, to those operating continuously, and for great distances, the most important mechanical movement in a ship, namely, the rudder.

One thing which it had not occurred to the authors to point out was that a mechanical connection between a fixed control wheel or lever and the rotating blades of an airscrew was of necessity a very much more complicated contrivance than the simple rotating hydraulic joint which conveyed the power from the fixed point to the rotating propeller in the case of the authors' airscrew, and for this reason a manually operated gear, which Mr. Lynam seemed to think

was so much simpler, was really a much more difficult and cumbrous mechanism than the simple hydraulic means which the authors have brought forward in their paper.

The answer the authors have made to Mr. Lynam on those points would serve as a reply to Dr. Watts, who they recognised as another authority on the airscrew. There was one point, however, which Dr. Watts had taken exception to apart from any argument by Mr. Lynam, and that was the use by the authors of the curves in Dr. Watts' book. Dr. Watts was under a misapprehension as to the curves which the authors had used; these were not taken from his variable pitch and surface curves, but from the curve for variable pitch only, page 293 of the book in question. For the purpose of comparison this curve has been super-imposed on the fixed pitch curve taken from page 149, both curves being for an angle of incidence of 4°. The curves were selected as average ones but, of course, the saving shown by the variable pitch propeller in any case must depend not only on the propeller's characteristics, but also on the rate at which the h.p. of the engine varied with the speed. The object of the authors in showing the curves was merely to indicate the general nature of the difference in efficiency and more especially to demonstrate the increased difference in the case of the super-charged engine.

The authors would point out that in the discussion various points which some speakers had raised had really been answered by the remarks of others and which, therefore, it was not necessary for them to deal with.

The remarks of Mr. S. H. Evans concerning multi-engined aircraft and particularly the twin-tandem four-engined machine, bring forward quite new points regarding the variable pitch airscrew. His further remarks in regard to slipstream drag, and the fact that in his opinion the variable pitch airscrew opens up a new lease of utility for the four-engined machine are a gratifying feature of his contribution.

Mr. Fage differentiates very clearly the value of the variable pitch airscrew for well established air routes and conditions under which it cruises at speeds which cannot be predetermined, and points out that the V.P. airscrew is needed to secure the best conditions in flight, and most efficient performance under extreme manœuvres and unknown heights.

In reply to the suggestion of Mr. North that figures should be given, the authors assure him that it is the intention of the Gloster Aircraft to carry out most exhaustive trials and publish the results they obtain.

Mr. Ralli has made a very important distinction between two types of aircraft and pointed out where the " compromise " propeller is unsatisfactory and where the advantages of variable pitch are very marked, amounting to as much as 10 per cent. in speed and 10 per cent. in take-off.

Mr. Walker, from another point of view, points out the circumstances under which the variable pitch propeller is necessary and that it has the advantage of allowing full r.p.m. on the climb. His suggestion that over a 2 : 1 speed range the propeller efficiency should not fall below 80 per cent. with a variable pitch airscrew is very significant. The remark of Mr. Walker regarding the geared Jupiter propeller in comparison with the ungeared is also of great interest. The authors are particularly grateful to Mr. Walker for supplementing their own figures No. 1 and 2 by the figure which he gives regarding the comparison of propeller efficiency for variable and fixed pitch.

In conclusion it may be observed that one remarkable feature both of the written and spoken discussion is that no criticism whatever has been made of the details of their hydraulic system, not one single correspondent having questioned the reliable nature of the automatic operation of the authors' system of variable pitch.

PROCEEDINGS

FOURTH MEETING, FIRST HALF, 63RD SESSION

A Joint Meeting with the Institution of Automobile Engineers was held at the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, on Thursday, November 3rd, 1927, when Mr. H. B. Taylor, A.F.R.Ae.S., read his paper on "High-Speed Compression-Ignition Engine Research." Colonel the Master of Sempill (Chairman of the Society) presided, and was supported by Major Beaumont (President of the Institution of Automobile Engineers).

Colonel the MASTER OF SEMPILL: This is the first joint meeting this session between the Institution of Automobile Engineers and the Royal Aeronautical Society. Since we met last year under similar conditions, when we had a lecture by Mr. Fedden, of the Bristol Co., on supercharging, I would like to inform more particularly the members of the Institution of Automobile Engineers that the Royal Aeronautical Society and the Institution of Aeronautical Engineers have amalgamated, and I am sure you will agree with me that this joining together of the technical forces concerned with the progress of aeronautics is all to the good. In so far as the Royal Aeronautical Society with which is now incorporated the Institution of Aeronautical Engineers, to give it its full title, is concerned, we welcome and always shall welcome these joint meetings, and as far as we are concerned we shall see that this is only one of many others that we hope are to follow.

The lecturer this evening is an Associate Fellow of the Society and has been senior officer of the Royal Aircraft Establishment for 8½ years. Before that he was associated with Messrs. Mirrlees, Bickerton & Day, and in fact it is no exaggeration to say that he has specialised in the subject he is going to deal with to-night for close on twenty years. I think we may congratulate ourselves now that the Official Secrets Act has been at least sufficiently lifted to enable Mr. Taylor to give us some account of the work he has been doing at the Royal Aircraft Establishment.

HIGH-SPEED COMPRESSION-IGNITION ENGINE RESEARCH

BY H. B. TAYLOR, A.F.R.AE.S.

When considering the compression-ignition engine for aeronautical purposes it is natural to ask the question: If successfully developed, what are the advantages to be gained from its use? Compared with the petrol engine, they may be summed up as follows:—

Reduction in specific fuel consumption.
Utilisation of cheap fuels of high flash-point.
Reduction of fire risk.
Elimination of electric-ignition system and elaborate precautions against interference with wireless reception.
Possibility of simple two-stroke operation.

Offset against these advantages may be placed the following disadvantages :—

Increase of structural weight necessitated by the higher working pressures in the cylinder.

Lower power output per unit volume of cylinder capacity.

Need for some form of preheating of the air to enable the engine to function at high altitudes.

In the preparation of this paper the application of the high-speed compression-ignition engine to aeronautical purposes has been the main consideration, although the successful development of such an engine will undoubtedly have an important influence over a very wide field, and will prove attractive for many purposes, mainly owing to the high economy to be obtained combined with the use of a cheap fuel.

The main problem to be solved in the development of this class of engine is that of the fuel-injection system, as the remainder of the engine may be of merely orthodox design. The ideal characteristics of any system of injection fall under the following heads :—

(*a*) Introduction of the fuel into the combustion chamber in the correct state for rapid combustion.

(*b*) Distribution of the fuel in the combustion chamber so that each particle of fuel readily associates with the required amount of oxygen.

(*c*) Control over the rate of admission of the fuel in order that an undesirable peak pressure does not occur in the cylinder.

The various systems of injection may be classified as follows :—

(i) Compressed-air injection through a mechanically-controlled valve.

(ii) Injection through a spring-loaded automatic valve by means of some form of " jerk " pump.

(iii) Injection through a mechanically-controlled valve, the fuel being stored at pressure in a receiver.

This method may be subdivided as follows :—

(*a*) Where the fuel pump is the sole metering device and the receiver pressure varies with the running conditions.

(*b*) Where the receiver is maintained at a constant pressure by means of a relief valve or suitable device, and the fuel is metered by the injection valve.

In considering these systems with reference to obtaining high brake mean pressures in excess of 100 lbs. per sq. in., compressed-air injection (i) probably fulfils the required conditions better than any known system ; very fine atomisation is created, a high degree of turbulence is caused by the air blast, giving very efficient mixing, and a good degree of control over the rate of admission is obtained by the mechanical control of the valve combined with variation of air blast pressure.

For a high-speed engine, however, the air compressor would probably bring along its own train of problems requiring solution, and for an aviation engine the additional weight and complication of a high-speed air compressor could not be faced with any degree of composure.

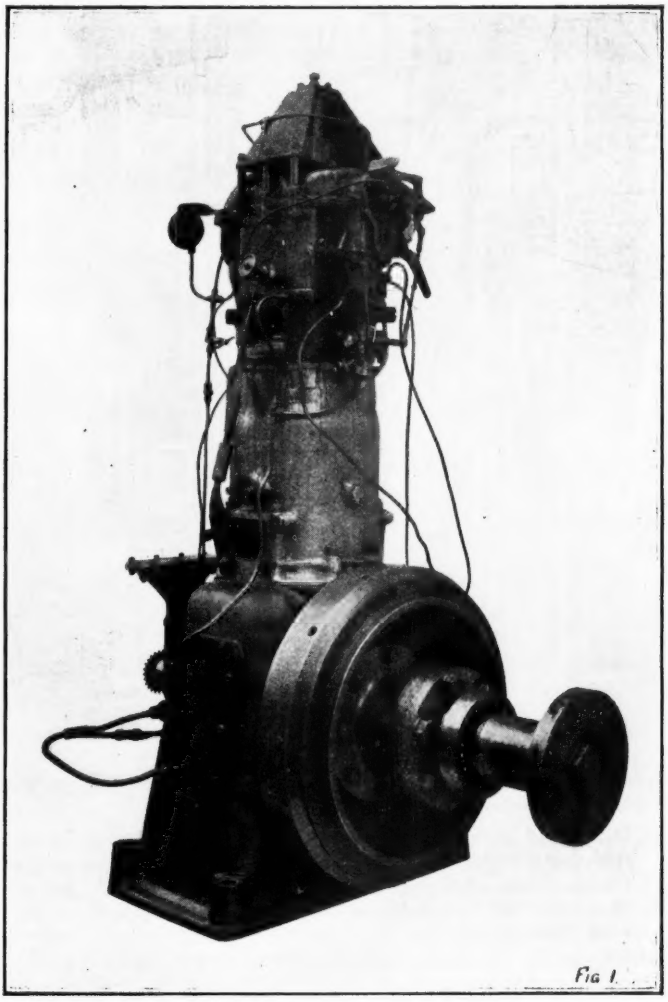
The " jerk " pump system (ii) appeals largely on account of its simplicity, but in the present state of knowlelge does not fulfil conditions (*a*) and (*c*) to the desired extent. This would appear to be due chiefly to the low injection pressure at the commencement and finish of the injection period combined with lack of control over the rate of admission of the fuel.

System (iii) (*a*) is more complicated than the " jerk " pump system owing to the mechanical operation of the valve, but more closely fulfils the required

conditions, as efficient control is obtained over the valve opening and closing, and the injection pressure is sensibly constant during the injection period.

Too much stress cannot be laid on the necessity of having a really rigid valve-actuating gear, owing to the small motions required and the high loading imposed. It would appear that an overhead camshaft is the most satisfactory method of obtaining the requisite rigidity.

System (iii) (*b*) is even more complicated, owing to the variations in valve

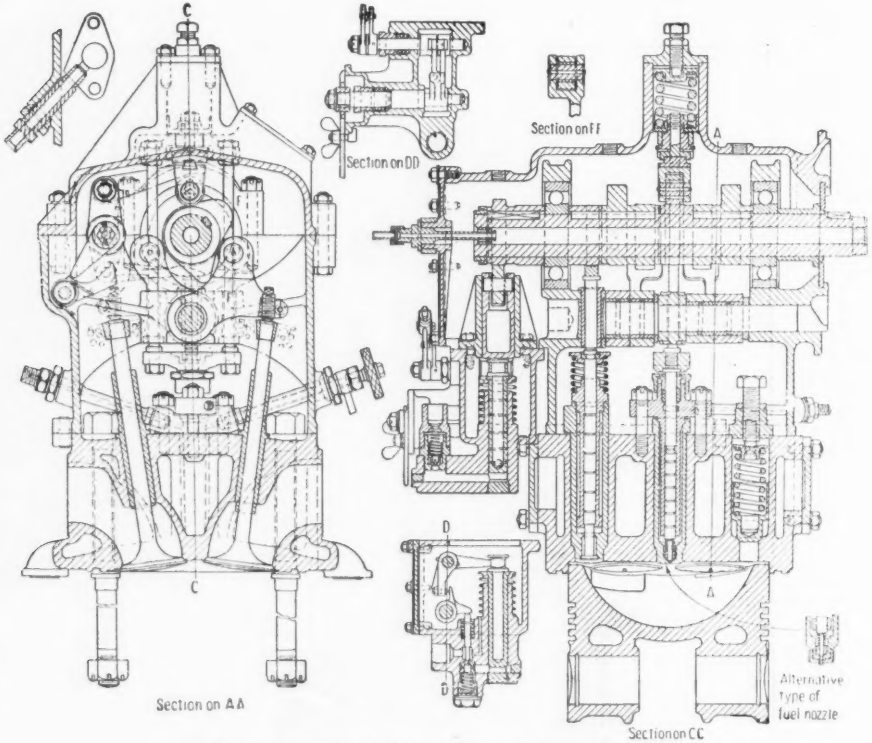


[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 1.

Engine used for tests.

opening required, but may possibly fulfil condition (*a*) more closely than system (iii) (*a*) as the injection pressure remains constant under all conditions of running. It may be, however, that for a flexible engine the injection pressure does not require to be so high at reduced speed and lower mean pressures, and under these conditions any advantage of this system over system (iii) (*a*) would be minimised.



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 2.

In defining the line of research to be followed at the Royal Aircraft Establishment the following considerations were borne in mind:—

(*a*) The use of a robust engine unit in order that the minimum trouble and delay due to mechanical breakdown should be experienced.

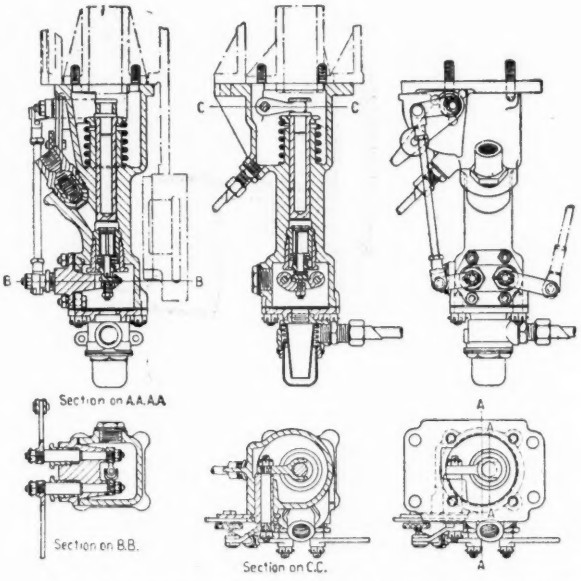
(*b*) The selection of a fuel-injection system which could be controlled reasonably well, and the actual time of opening and closing of the valve determined.

The unit chosen for the work is known as the 20.T., and had been used for the determination of the performance of a large cylinder working on the four-stroke constant-volume cycle. The bore is 8in. and the stroke 11in., the designed normal speed being 1,250 revs. per minute. Conversion to compression-ignition working necessitated the manufacture of a new cast-iron cylinder head, Fig. 2, incorporating two inlet and two exhaust valves with a central fuel-injection valve,

the whole being operated by a single overhead camshaft, at the extremity of which was an eccentric for driving the fuel pump. A pressure-relief valve and an indicator connection in the cylinder head were also provided. A new piston was fitted to give the required compression-ratio, namely 12 : 1, and the crankshaft and connecting rod were replaced by parts of greater strength. The designed normal speed of the modified unit was 1,000 revs. per minute, with a maximum allowable speed of 1,200 revs. per minute.

Fig. 1, Plate I., shows a photograph of the unit.

The fuel-injection system used falls within category (iii) (*a*), and is of a well-known type wherein fuel is delivered into a receiver by means of a pump controlled on the suction valve, and the injection valve is positively opened by a cam and closed by a spring.



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 2A.

Fuel pump as modified.

There is no by-pass relief valve in the system, the pump being the metering device. The pressure in this system will automatically become that required to force into the cylinder through the orifice provided and in the time available such quantity of fuel as the pump delivers into the system. For example, at a given engine speed the larger the quantity of fuel delivered by the pump the higher will be the injection pressure, other conditions being unaltered. This system is illustrated diagrammatically in Fig. 3. The time of injection of the fuel can be varied while the engine is running, but the period remains fixed.

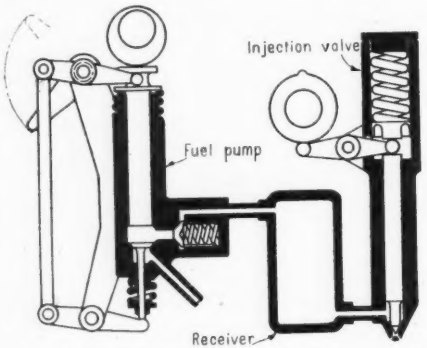
The use of shale oil fuel was adopted, as this oil is fairly clean, and it was desired to reduce stoppages due to dirt to the minimum. This fuel has a specific gravity of 0.86.

In order that definite comparisons could be obtained with regard to the effect of different conditions on the performance of the engine in carrying out the actual tests—

(i) The maximum quantity of fuel injected per cycle was fixed at an amount that reasonably could be expected to combine efficiently with the amount of air present.

(ii) The maximum cylinder pressure was maintained constant for any series of tests by adjustment of the injection timing, and was measured by means of the R.A.E. electrical indicator.

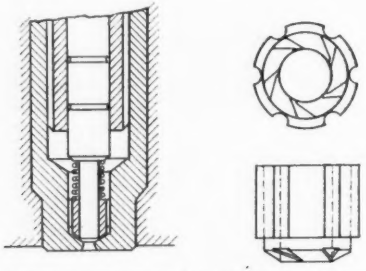
For the first tests, which were commenced in November, 1921, a speed of 600 revs. per minute was fixed, with occasional tests at higher speeds, as it was anticipated that high-speed operation would add to the difficulty of obtaining



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 3.

Diagram of fuel injection system. 20.T compression-ignition unit.



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 4.

Diagram of slot type nozzle. 20.T compression-ignition engine.

good results. The type of nozzle first used gave a spray of the "soft" variety, the fuel passing along tangential slots, the inner extremities of which were uncovered by the valve spindle as it lifted; by this means a whirl was imparted to the spray, which was very finely divided but had little penetrating quality. This type of nozzle is shown in Fig. 4.

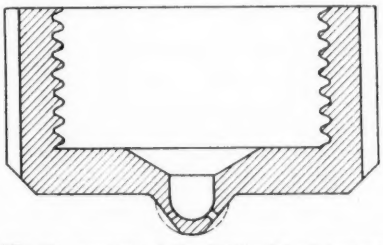
The variations available with this nozzle being the dimensions of the slots, which were of square section, tests were made with the following sizes :—0.008in.,

0.010in., 0.012in. and 0.014in. The results were very disappointing, as will be seen by reference to Table I., which are those obtained with the nozzle having 0.010in. slots.

The conclusion drawn from these tests was that this class of spray had insufficient penetrating power, which had the effect of concentrating the fuel in the vicinity of the injection orifice, giving inefficient mixing, although the combustion chamber was small compared with most commercial engines of the type. It was therefore decided to carry out tests with another type of nozzle having situated below the valve seat a small hemispherical chamber out of which led several small holes. This type of nozzle was known to possess good penetrating qualities, and is shown in Fig. 5, the first one tested having five holes 0.0145in. diameter drilled at a cone angle of 120 degrees. This alteration gave a marked improvement in performance, brake mean effective pressure in excess of 100 lbs. per sq. in. being obtained at 1,000 revs. per minute with a fuel consumption of 0.45 lbs. per brake horse-power hour without exceeding a maximum pressure in the cylinder of 650 lbs. per sq. in.; as a result all testing at speeds below 800 revs. per minute was discontinued.

TABLE I.

	B.M.E.P., lb. per sq. in.		Fuel cons. lb. per B.H.P. per hour.		Injection pressure.
R.P.M.	650lb. cyl. press.	700lb. cyl. press.	650lb. cyl. press.	700lb. cyl. press.	lb. per sq. in.
600	73.2	79.6	0.632	0.590	2,040
1,000	66.8	72.0	0.695	0.650	3,340



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 5.

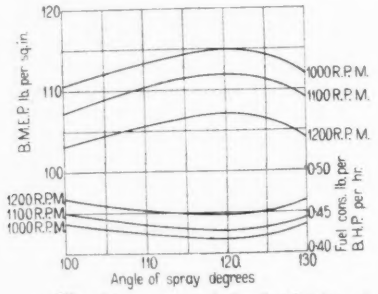
Diagram of hole type nozzle. 20.T compression-ignition engine.

Investigation was next carried out in respect of the best cone angle at which to drill the holes, and the effect of variations in the number, diameter and length of the holes; in this connection a reference to the manufacture of these sprayers will not be without interest.

The blank is first turned, care being taken to ensure that the inside of the hemisphere is truly concentric with the outside. The holes are then marked off and the sprayer mounted on an adjustable angle jig. A watchmaker's drilling machine is used with a drill a size smaller than the hole required, the final size being obtained with the correct size drill used in a hand chuck. Flats are then filed at the end of the holes until the requisite length of hole is obtained. Final adjustment of the hole diameter is carried out by flow calibration through each hole under a head of petrol, the capacity of the sprayer quoted in the diagrams being the total flow in c.c. per minute under a 13ft. head.

Fig. 6 shows the effect of variation of cone angle, an angle of 120 degrees giving the best results. It is of interest to note that the volume of air included in

this cone angle is approximately one-half of the volume on the outside with the piston at a position giving the mean volume during injection.

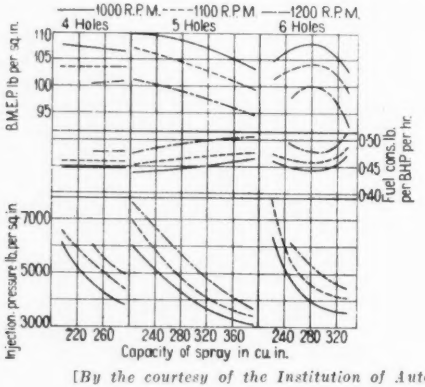


[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 6.

Diagram showing effect on performance of variation of angle of spray, with hole size giving best results.
20.T compression-ignition engine.

Fig. 7 shows the effect of variation of hole diameter with four, five and six holes. Each of the four-hole sprayers gave sensibly the same result, leading to the conclusion that the larger holes gave better distribution in the combustion chamber due to the more divergent spray, and that this compensated for the reduced atomisation due to the large hole, giving about the same net result.



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 7.

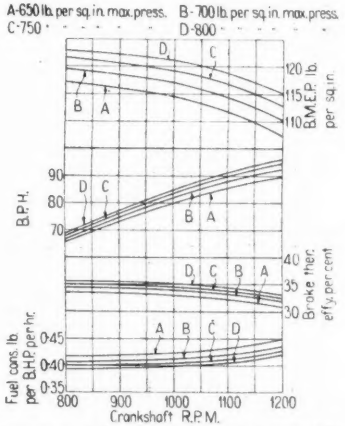
20.T compression-ignition engine.

Of the five-hole sprayers, the one having the smallest holes gave the best results, the distribution evidently being good with approximately the correct degree of atomisation and penetration. Any increase of hole size results in a more divergent spray and reduced performance, probably due to reduced atomisation; the jets probably interfere with one another, giving rich zones with consequent inferior combustion.

Regarding the tests of the six-hole sprayers, one having a capacity of 285 c.c. gave the best results, any increase or decrease in hole size giving an inferior

performance. Curiously enough, the holes in this sprayer were the same diameter as those in the best five-hole sprayer, namely 0.0145in. If we accept the previous findings as correct, we can only conclude that holes smaller than this give a finer spray but with reduced penetration, as with six holes a narrow angle of divergence would be required for good distribution; reduced penetration, therefore, would appear to afford an explanation of the inferior results obtained with small holes. Larger holes than 0.0415in. diameter give a reduced performance, owing to increased spray interference, as in the case of the five-hole sprayers with large holes.

As a confirmation of the above theory of jet interference with wide angles, five-hole sprayers were constructed with holes 0.016in. and 0.018in. diameter, and 0.02in., 0.03in. and 0.04in. long; all previous sprayers had holes 0.02in. long. This was an attempt to narrow the jet angle from a large hole by making the hole longer and thus improve the distribution. Holes 0.016in. diameter gave the best results when made 0.03in. long, and 0.018in. diameter holes gave sensibly the



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 8.

20.T compression-ignition engine.

same performance with lengths of 0.03in. and 0.04in., but in all cases better than with holes 0.02in. long, showing that the distribution was improved by reducing the jet angle. In no case, however, was the performance with larger and longer holes so good as that obtained with holes 0.0145in. diameter and 0.02in. long, and it would appear that the requisite degree of atomisation is only attained when holes of this size are used.

Some brief tests were carried out to determine the optimum compression ratio for this cylinder, pistons being fitted giving ratios of 10.5 : 1, 11 : 1 and 12 : 1. The two higher ratios gave sensibly the same results, the performance with the lowest ratio being inferior. The optimum ratio would appear to be between 11 : 1 and 12 : 1, but the higher ratio would probably give the better starting in cold weather and enable the engine to function at a higher altitude.

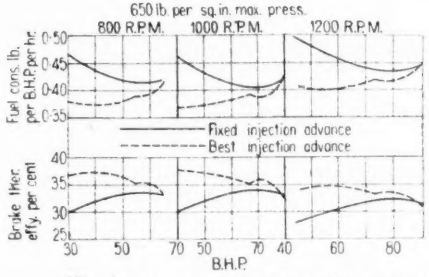
From these tests the conclusion was reached that the best sprayer for this cylinder is one having five holes 0.0145in. diameter, 0.02in. long drilled at a cone angle of 120 degrees; a complete calibration of the engine with this sprayer was accordingly carried out, and the results are given in Tables II., III. and IV., and shown graphically in Figs. 8, 9 and 10. Table II. and Fig. 8 show the

TABLE II.

Max. cyl. press., lb. per sq. in.	R.P.M.	B.H.P.	B.M.E.P. lb. per sq. in.	Fuel cons., lb. per B.H.P. per hour.	I.H.P.	I.M.E.P., lb. per sq. in.	Fuel cons., lb. per I.H.P. per hour.	Brake th. effy. per cent.	Indicated th. effy. per cent.	Excess air coeff.	Mech. effy.	Injection press., lb. per sq. in.	Injection timing, degrees early.	B.H.P.	Remarks
	800	65.4	117.0	0.415	71.8	128.4	0.378	33.5	36.8	—	0.911	4,250	13	65.4	Comp.-ratio, 11.5 : 1.
	900	73.1	116.3	0.418	80.9	128.7	0.378	33.2	36.8	—	0.904	5,600	13	73.1	
650	1,000	79.9	114.3	0.423	89.1	127.4	0.380	32.8	36.6	1.31	0.896	6,350	11	79.9	Comp.-ratio, 12.05 : 1.
	1,100	85.7	111.5	0.433	96.3	125.3	0.385	32.1	36.1	—	0.890	7,100	11.5	85.7	
	1,200	89.7	107.0	0.450	101.8	121.4	0.396	30.9	35.1	1.29	0.881	8,050	10.5	89.7	
	800	66.7	119.5	0.405	73.1	130.9	0.370	34.3	37.6	—	0.913	4,300	15.5	66.7	Comp.-ratio, 11.5 : 1.
	900	74.5	118.4	0.408	82.3	130.8	0.370	34.1	37.6	—	0.905	5,600	15	74.5	
700	1,000	81.8	117.0	0.412	91.0	130.1	0.371	33.7	37.5	1.31	0.899	6,500	13.5	81.8	Comp.-ratio, 12.05 : 1.
	1,100	88.0	114.5	0.419	98.6	128.3	0.374	33.2	37.2	—	0.893	7,150	12.5	88.0	
	1,200	92.3	110.0	0.435	104.4	124.4	0.385	31.9	36.1	1.30	0.883	8,350	13.5	92.3	
	800	68.0	121.8	0.398	74.4	133.1	0.364	34.9	38.2	—	0.914	4,350	17.5	68.0	Comp.-ratio, 11.5 : 1.
	900	75.8	120.5	0.400	83.6	132.9	0.363	34.7	38.3	—	0.907	5,600	17.5	75.8	
750	1,000	83.2	119.0	0.404	92.4	132.1	0.365	34.4	38.1	1.32	0.901	6,500	15.5	83.2	Comp.-ratio, 12.05 : 1.
	1,100	89.9	117.0	0.411	100.5	130.8	0.368	33.8	37.8	—	0.894	7,250	16	89.9	
	1,200	94.6	112.8	0.426	106.7	127.2	0.378	32.6	36.8	1.29	0.887	8,350	15.5	94.6	
	800	68.9	123.2	0.392	75.3	134.7	0.359	35.4	38.7	—	0.916	4,500	19.5	68.9	Comp.-ratio, 11.5 : 1.
	900	76.7	122.0	0.394	84.5	134.4	0.358	35.3	38.8	—	0.908	5,600	19	76.7	
800	1,000	84.6	121.1	0.398	93.8	134.2	0.360	34.9	38.6	1.31	0.902	6,550	17.5	84.6	Comp.-ratio, 12.05 : 1.
	1,100	91.4	119.0	0.405	102.0	132.8	0.363	34.3	38.3	—	0.896	7,200	18	91.4	
	1,200	96.2	114.8	0.421	108.3	129.2	0.374	33.0	37.2	1.28	0.888	8,350	17	96.2	

variation in performance with cylinder pressures between 650 lbs. per sq. in. and 800 lbs. per sq. in., a progressive improvement being shown as the pressure is increased. These observations were made with the maximum fuel charge, which gave an excess-air coefficient of approximately 1.3, *i.e.*, the air present in the cylinder was 30 per cent. in excess of theoretical requirements for complete combustion. At the designed speed of 1,000 revs. per minute a brake mean effective pressure of 121 lbs. per sq. in. was obtained with a fuel consumption of 0.4 lbs. per brake horse-power hour.

It is interesting to compare this result with the performance of the same unit when running on petrol at 1,000 revs. per minute when the brake mean effective pressure was 134 lbs. per sq. in. and the fuel consumption 0.49 lb. per brake horse-power per hour. We thus see that although the power output is reduced by less than 10 per cent. when running on oil fuel, the consumption is down by more than 18 per cent. From this we may deduce that the increase in engine weight will be compensated by the reduction in fuel used if the flight be of a certain minimum duration. For long flights, therefore, the disadvantages of increased engine weight and reduced power output disappear. The approximate minimum length of flight will be indicated when the probable increase in engine weight is considered.



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 9.

Constant speed variable torque curves.
20.T compression-ignition engine.

Table III. and Fig. 9 show the results obtained at constant speeds and varying torque with 650 lbs. per sq. in. maximum cylinder pressure at full torque—

(*a*) With fixed injection-timing and lower maximum pressures at reduced torque.

(*b*) With the injection-timing adjusted to maintain the maximum pressure throughout.

Table IV. and Fig. 10 give similar data for a maximum cylinder pressure of 800 lbs. per sq. in. A peculiar kink occurs in most of these consumption curves, and this is not accounted for at present. It may be that the distribution is affected by the manner in which the jets strike the piston under certain circumstances, which becomes less important as the amount of fuel injected is still further reduced.

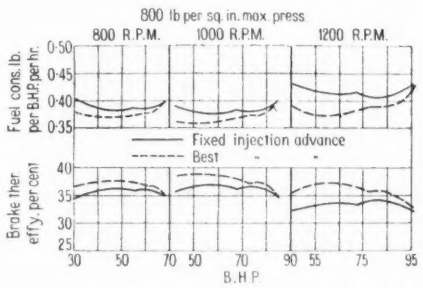
An examination of these results shows that a distinct advantage is to be gained by increasing the injection advance as the amount of fuel injected is reduced, and thereby maintaining the maximum cylinder pressure.

A further advantage over the petrol engine now reveals itself, in that as the torque is reduced so is the specific fuel consumption, whereas the reverse is usually the case with the petrol engine.

TABLE III.

Max. cyl. press., lbs. per sq. in.	R.P.M.	B.H.P.	B.M.E.P., lbs. per sq. in.	Fuel cons., lb. per B.H.P. per hr.	I.H.P.	I.M.E.P., lb. per sq. in.	Fuel cons., lb. per I.H.P. per hr.	Brake eff., per cent.	Indicated eff., per cent.	Excess air coeff.	Mech. effy.	Injection press., lb. per sq. in.	Injection timing degrees early.	B.H.P.	Remarks.
630		64.6	115.6	0.418	71.0	127.0	0.380	33.2	36.5	—	0.910	4,700		64.6	Injection timing fixed to give
590		60.0	107.3	0.415	66.4	118.7	0.376	33.5	36.9	—	0.904	4,050		60.0	650lb. per sq. in. max. cyl.
525	800	50.0	89.4	0.416	56.4	100.8	0.370	33.4	37.5	—	0.887	3,300	11.5	50.0	press. with full fuel charge.
480		40.0	71.5	0.435	46.4	82.9	0.375	31.9	37.0	—	0.863	2,150		48.0	Max. cyl. press. allowed to
435		30.0	53.6	0.465	36.4	65.0	0.384	29.9	36.2	—	0.824	1,700		30.0	fall at reduced loads.
		65.0	116.3	0.417	71.4	127.7	0.380	33.2	36.5	—	0.911	4,700	12.5	65.0	650lb. per sq. in. max. cyl.
		60.0	107.3	0.393	66.4	118.7	0.355	35.4	39.1	—	0.904	4,350	14	60.0	press. maintained by increas-
650	800	50.0	89.4	0.378	56.4	100.8	0.336	36.7	41.3	—	0.887	2,450	20	50.0	ing injection advance at re-
		40.0	71.5	0.373	46.4	82.9	0.322	37.2	43.1	—	0.863	1,700	27	40.0	duced loads.
		30.0	53.6	0.380	36.4	65.0	0.313	36.6	44.3	—	0.824	1,200	31.5	30.0	
655		80.0	114.6	0.421	89.2	127.7	0.378	33.0	36.7	1.31	0.897	6,300		80.0	Injection timing fixed to give
580		70.0	100.2	0.407	79.2	113.3	0.360	34.1	38.6	1.54	0.884	5,850		70.0	650lb. per sq. in. max. cyl.
530	1,000	60.0	85.9	0.412	69.2	99.0	0.358	33.7	38.8	1.79	0.867	3,700	12	60.0	press. with full fuel charge.
485		50.0	71.6	0.432	59.2	84.7	0.365	32.1	38.1	2.05	0.845	3,050		50.0	Max. cyl. press. allowed to
445		40.0	57.3	0.461	49.2	70.4	0.375	30.1	37.0	2.39	0.813	2,300		40.0	fall at reduced loads.
		79.5	113.9	0.426	88.7	127.0	0.382	32.6	36.4	1.30	0.896	6,250	12	79.5	650lb. per sq. in. max. cyl.
		70.0	100.2	0.386	79.2	113.3	0.341	36.0	40.7	1.63	0.884	4,700	16	70.0	press. maintained by increas-
650	1,000	60.0	85.9	0.384	59.2	99.0	0.333	36.2	41.7	1.93	0.867	3,350	20.5	60.0	ing injection advance at re-
		50.0	71.6	0.373	59.2	84.7	0.315	37.2	44.1	2.37	0.845	2,450	24.5	50.0	duced loans.
		40.0	57.3	0.368	49.2	70.4	0.299	37.7	46.4	3.00	0.813	1,700	29.5	40.0	
630		90.0	107.3	0.443	102.1	121.7	0.391	31.3	35.5	1.31	0.881	8,100		90.0	Injection timing fixed to give
585		80.0	95.4	0.433	92.1	109.8	0.376	32.1	36.9	1.50	0.869	6,750		80.0	650lb. per sq. in. max. cyl.
550	1,200	70.0	83.5	0.439	82.1	97.9	0.374	31.6	37.1	1.68	0.853	5,800	12	70.0	press. with full fuel charge.
535		60.0	71.5	0.454	72.1	85.9	0.378	30.6	36.7	1.89	0.832	4,600		60.0	Max. cyl. press. allowed to
505		50.0	59.6	0.478	62.1	74.0	0.385	29.0	36.1	2.17	0.805	3,550		50.0	fall at reduced loads.
		90.0	107.3	0.445	102.1	121.7	0.393	31.2	35.3	1.30	0.881	7,900	12	90.0	650lb. per sq. in. max. cyl.
		80.0	95.4	0.414	92.1	109.8	0.360	33.5	38.6	1.56	0.869	6,650	15.5	80.0	press. maintained by increas-
650	1,200	70.0	83.5	0.412	82.1	97.9	0.352	33.7	39.4	1.79	0.853	5,300	20.5	70.0	ing injection advance at re-
		60.0	71.5	0.402	72.1	85.9	0.335	34.5	41.4	2.15	0.832	4,050	23.5	60.0	duced loans.
		50.0	59.6	0.402	62.1	74.0	0.324	34.5	42.8	2.58	0.805	2,750	30	50.0	

The maximum recorded brake thermal efficiency was 38 per cent. obtained at 1,000 revs. per minute, the brake mean effective pressure being 78 lb. per sq. in., and the fuel consumption 0.358 lb. per brake horse-power per hour. The best indicated thermal efficiency was 46.7 per cent. at 1,000 revs. per minute,

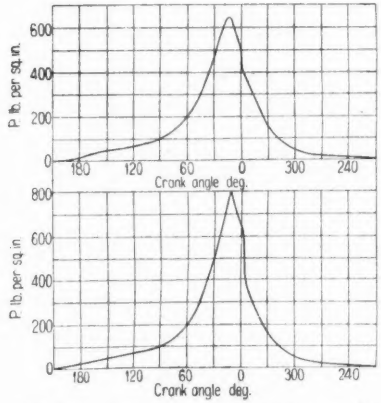


[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 10.

Constant speed variable torque curves.
20 T. compression-ignition engine.

the indicated mean effective pressure being 74.2 lb. per sq. in., and the fuel consumption 0.297 lb. per indicated horse-power per hour. Throughout these tests the indicated results have been obtained by assuming the indicated power to be the sum of the brake power and the power required to motor the engine,



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 11.

Indicator cards taken at 1,000 *revs. per minute.*

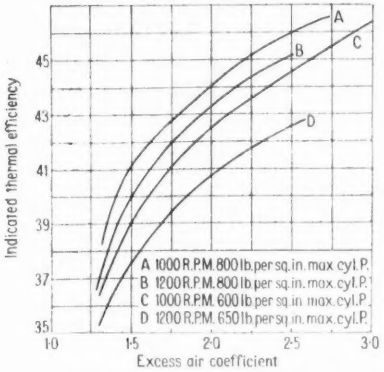
and the excess-air coefficient determined by direct measurement of the volumetric efficiency by the air-box method. Typical indicator diagrams taken at full load at 1,000 revs. per minute are shown in Fig. 11.

TABLE IV.

Max. cyl. press., lbs. per sq. in.	R.P.M.	B.H.P.	B.M.E.P., lbs. per sq. in.	Fuel cons., lb. per B.H.P. per hr.	I.H.P.	I.M.E.P., lb. per sq. in.	Fuel cons., lb. per I.H.P. per hr.	Brake th. effy. per cent.	Indicated th. effy. per cent.	Excess-air coeff.	Mech. effy.	Injection press., lb. per sq. in.	Injection timing degrees early.	B.H.P.	Remarks.
800		68.3	122.3	0.398	74.7	133.7	0.364	34.9	38.1	—	0.914	4,700		68.3	Injection timing fixed to give 800lb. per sq. in. max. cyl. press. with full fuel charge. Max. cyl. press. allowed to fall at reduced loads.
740		60.0	107.3	0.385	66.4	118.7	0.348	36.1	39.9	—	0.904	3,700		60.0	
635	800	50.0	89.4	0.383	56.4	100.8	0.339	36.3	41.0	—	0.887	2,450	20	50.0	
570		40.0	71.5	0.386	46.4	82.9	0.333	36.0	41.7	—	0.863	1,900		40.0	
510		30.0	53.6	0.404	36.4	65.0	0.333	34.4	41.7	—	0.824	1,400		30.0	
		67.8	121.3	0.395	74.2	132.7	0.361	35.2	38.4	—	0.914	4,600	20	67.8	800lb. per sq. in. max. cyl. press. maintained by increasing injection advance at reduced loads.
800		60.0	107.3	0.378	66.4	118.7	0.342	36.7	40.6	—	0.904	3,300	24	60.0	
	800	50.0	89.4	0.370	56.4	100.8	0.328	37.5	42.3	—	0.887	2,300	30.5	50.0	
		40.0	71.5	0.371	46.4	82.9	0.320	37.4	43.4	—	0.863	1,750	36	40.0	
670		30.0	53.6	0.380	36.4	65.0	0.313	36.5	44.3	—	0.824	1,100	37	30.0	
800		84.1	120.5	0.400	93.3	133.6	0.361	34.7	38.4	1.32	0.902	6,500		84.1	Injection timing fixed to give 800lb. per sq. in. max. cyl. press. with full fuel charge. Max. cyl. press. allowed to fall at reduced loads.
755		75.0	107.3	0.378	84.2	120.4	0.337	36.7	41.2	1.55	0.891	5,100		75.0	
660	1,000	65.0	93.0	0.380	74.2	106.1	0.333	36.5	41.7	1.80	0.876	3,600	20	65.0	
605		55.0	78.7	0.375	64.2	91.8	0.321	37.0	43.2	2.14	0.857	2,850		55.0	
540		45.0	64.4	0.384	54.2	77.5	0.319	36.2	43.5	2.56	0.830	2,200		45.0	
		84.2	120.6	0.401	93.4	133.7	0.362	34.6	38.3	1.31	0.902	6,400	19	84.2	800lb. per sq. in. max. cyl. press. maintained by increasing injection advance at reduced loads.
		75.0	107.3	0.372	84.2	120.4	0.332	37.3	41.8	1.57	0.891	5,000	22	75.0	
800	1,000	65.0	93.0	0.363	74.2	106.1	0.318	38.2	43.6	1.89	0.876	3,150	30	65.0	
		55.0	78.7	0.358	64.2	91.8	0.307	38.8	45.2	2.24	0.857	2,500	33.5	55.0	
		45.0	64.4	0.359	54.2	77.5	0.298	38.7	46.6	2.73	0.830	1,950	37	45.0	
780		94.8	113.0	0.429	106.9	127.4	0.380	32.4	36.5	1.28	0.887	8,850		94.8	Injection timing fixed to give 800lb. per sq. in. max. cyl. press. with full fuel charge. Max. cyl. press. allowed to fall at reduced loads.
705		85.0	101.3	0.408	97.1	115.7	0.357	34.0	38.9	1.49	0.875	7,400		85.0	
665	1,200	75.0	89.4	0.409	87.1	103.8	0.352	33.9	39.4	1.69	0.861	5,700	18	75.0	
600		65.0	77.5	0.411	77.1	91.9	0.347	33.8	40.0	1.93	0.843	4,350		65.0	
580		55.0	65.6	0.418	67.1	80.0	0.343	33.2	40.5	2.26	0.819	3,600		55.0	
		95.7	114.1	0.427	107.8	128.5	0.379	32.5	36.6	1.28	0.888	8,400	18	95.7	800lb. per sq. in. max. cyl. press. maintained by increasing injection advance at reduced loads.
		85.0	101.3	0.391	97.1	115.7	0.342	35.5	40.6	1.55	0.875	6,800	22.5	85.0	
800	1,200	75.0	89.4	0.386	87.1	103.8	0.332	36.0	41.8	1.79	0.861	4,650	27	75.0	
		65.0	77.5	0.375	77.1	91.9	0.316	37.0	43.9	2.13	0.843	3,600	31.5	65.0	
		55.0	65.6	0.374	67.1	80.0	0.307	37.1	45.2	2.52	0.819	2,700	37	55.0	

Fig. 12 shows the indicated thermal efficiency plotted against excess-air coefficient; by this means mechanical and volumetric efficiency effects are eliminated and the relative combustion efficiency is obtained. From these curves it will be seen that greater advantage is obtained from the use of the higher maximum pressures at 1,200 revs. per minute than at 1,000 revs. per minute, which indicates the probable necessity for using high cylinder pressures for high-speed operation.

As regards the increase in engine weight compared with the petrol engine, the chief components requiring additional stiffness will be the crankshaft, crankcase and connecting rods; slightly heavier pistons may be required, owing to the necessity for additional strength in the crown, and the cylinder attachments will



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 12.

Effect on thermal efficiency of variations in excess-air coefficient.

probably require strengthening. The weight of the injection system may be considered as offset by the carburettors and magnetos of the petrol engine.

Taking these factors into consideration, it is estimated that the compression-ignition engine will weigh from 1 to 2 lb. per brake horse-power more than the corresponding size and type of petrol engine, the lower figure applying to the air-cooled radial engine, and the higher figure to the water-cooled engine with the cylinders in line.

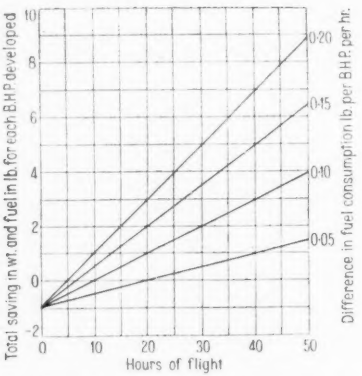
Fig. 13 illustrates graphically the saving in total weight obtained with a compression-ignition engine weighing 1 lb. per brake horse-power more than a petrol engine, but having a lower fuel consumption, considered with reference to hours of flight.

Taking a specific case of an engine consuming 0.10 lb. per brake horse-power per hour less, but weighing 1 lb. per brake horse-power more, than another engine, it will be seen that no saving in total weight is obtained under ten hours' flight, but that a progressive saving is obtained as the duration of the flight is increased. (Actually, a saving of 0.25 lb. per brake horse-power per hour is not outside the bounds of possibility.)

Similar information may be deduced for other differences in fuel consumption, and a direct correction made for variations in the difference in engine weight.

Considered in this light, the advantage of using such an engine for airship operation is obvious, and for long-distance heavier-than-air flights the reduction in total initial weight may be such as to allow the machine to leave the ground, whereas without such reduction flight becomes impossible.

The utilisation of cheap fuels having a high flash-point will undoubtedly reduce the cost of operation and risk of fire, which is an important consideration, especially in the case of civil transport, where risk to passengers is of paramount importance if the public is to be attracted to flying. For this reason alone every endeavour should be made to encourage rapid progress in the development of high-speed compression-ignition engines, even if the early full-scale results do not entirely come up to expectations.



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 13.

Compression-ignition engine weighing 1 *lb. per brake horse-power more than corresponding petrol engine at operating output.*

One of the main drawbacks to the use of a two-stroke aviation engine running on petrol has been the loss of mixture which occurs through the exhaust port, which loss can only be overcome by an elaborate system of porting, or valve arrangement, or the injection of fuel during the compression stroke. The difficulties met with, however, have been so great that no successful two-stroke aviation engine has yet been developed, and in those types which have shown any promise the simplicity of the normally ported two-stroke engine has disappeared.

The compression-ignition engine is concerned with the compression of air alone, and the simple ported two-stroke construction does not lead, in this case, to a direct loss of fuel through the exhaust ports.

This class of engine therefore lends itself more readily to two-stroke working than does the petrol engine, and when successfully developed may show very favourable weight/power ratios.

In presenting these results and observations the author has attempted to show what prospects the compression-ignition engine has for aeronautical use. When work has been done to develop means of obtaining good combustion at much higher speeds of rotation, thereby enabling smaller cylinders to be used, the time will be in sight when this class of engine will prove a serious competitor to the petrol engine, which at present deservedly holds undisputed sway in the aeronautical field.

This paper would not be complete without a reference to the valuable advice received from Professor C. J. Hawkes, of Armstrong College, Newcastle-on-Tyne, throughout the progress of the investigations, and to the assistance given by the Staff of the Engine Department, R.A.E.

Discussion

Colonel The Master of Sempill: We must all regret that the author is only permitted to lift a very small corner of the veil, and that he has not been in a position to disclose to us fully all that he has been doing at the R.A.E. From the aeronautical standpoint, this work is of immense value, particularly in respect of the reduction of fire risk on aircraft. A further advantage is that the compression-ignition engine would render possible flights which are not possible to-day with the internal combustion engine.

Captain J. S. Irving: I would like to sympathise with the author in having to base his paper on such, to him, rather old experiments, seeing that they were commenced in September, 1921, and I hardly think he would be disclosing any official secrets if he were to tell us when he actually completed these tests, and we can assume that his knowledge has advanced very considerably since. Practically all the development work on compression-ignition engines from the earliest days has been aimed at devising some means of accurately metering the fuel into the cylinder and ensuring that it shall be brought into close contact with the air in the cylinder. Many different devices have been tried, and, incidentally, I would like the author to tell us why he should assume in his paper that a lower compression-pressure will be required at lower speeds. In a report issued by the American Aeronautical Society it was conclusively proved that the penetration of the jet of fuel was independent of the normal variations of the compression in the cylinder, and this was illustrated by photographs showing the penetrative force of various jets, under different conditions. Considering that the main difficulty with the development of the high-speed compression-ignition engine is to obtain intimate association between the oxygen in the cylinder and the fuel, practically all the English experimental work has been on the lines of improving known fuel-injection methods, but on the Continent there is a tendency to break new ground. One German firm is developing a design in which the fuel jet is directed into the mouth of a venturi-shaped passage which is formed in the piston crown and connects with a main air chamber in the piston crown, which is the actual compression chamber when the piston is at or very near the top dead-centre; the fuel jet ignites in the mouth of the venturi, and as the piston moves downwards the burnt gas passes to the top of the piston and the flame is replenished by air from the air chamber. No very exceptional results have yet been obtained, but they have been encouraging and have proved that the rate of combustion varies with the speed of the engine up to 2,400 revs. per minute, the maximum speed obtained. I consider that there is a very big future for this line of development, because it is easier to control the air and direct the air to the jet of fuel than it is to ensure that the jet of fuel shall be brought into contact with the air in the present English way. Seeing that with a single-cylinder engine developing 50 h.p. the actual amount of fuel to be injected per injection is only a fraction of an ounce, which means that with a five-hole jet each jet must be infinitesimal in diameter, it has to be acknowledged that the difficulty of controlling such quantities of liquid and ensuring that it shall have a very definite penetrative power is not easy to overcome.

The author has restricted himself in the experiments described to 1,200 revs. per minute, but could he not tell us a little more about the actual speed obtained with compression-ignition engines, because there are already several different types of commercial compression-ignition engines running at speeds up to 2,000 revs. per minute? There are two main advantages of the compression-ignition engine, namely, economy and absence of fire risk. As regards the absence of fire risk, experiments are being made with a modified type of 4-stroke petrol engine, burning heavy fuel, and the heavy fuel is injected into a partial vacuum created

on the underneath side of the piston, together with a very small proportion of air; this causes very fine vaporisation, and the gas so formed is admitted into the usual induction pipe as used on a carburettor engine. With regard to economy, petrol engines are now being developed to run at very high compression ratios, using various " anti knock " mixtures, such as tetra-ethyl lead, and by this means considerable economy in fuel is possible. It may be that in the near future a new fuel will be obtainable which will reduce the fire risk and enable very high compression ratios to be used.

In connection with fuel consumption, in some trials held by the French Automobile Club the petrol consumption of the winning car was in the region of 0.25lb. of petrol per horse-power per hour, but the lubricating oil consumption was about 0.75lb. per horse-power per hour, due to the competitor having connected his carburettor air intake to the engine crankcase, and so using air saturated with lubricating oil. The author has not mentioned what the consumption of lubricating oil was, but it may be that with the low consumption of fuel mentioned by him, namely, 0.356lb. per horse-power per hour, the lubricating oil consumption was rather excessive.

Mr. W. A. Tookey: Captain Irving's remarks in regard to the consumption of lubricating oil and fuel oil respectively, can best be answered by closely studying the figures given in the Tables. If from these figures we make other computations and proceed to make other charts, such as those in Figs. 14 and 15 which refer to the tests in Table III., I think it will be found that the results are really correlative and that they bear the stamp of truth; even the low fuel oil consumption of 0.296lb. per indicated horse-power per hour is above suspicion. Comparing the indicated horse-power thermal efficiency with the Air Standard for the lowest indicated horse-power per hour consumption, I find that it is 73 per cent. of the Air Standard, and that, for the mixture strength in that particular line of the Table, is quite in accord with my expectations. If a still more critical mathematical analysis is made, I find that the value of γ (in the thermal efficiency formula $(1-(1r)\gamma^{-1})$) will be 1.25, and that again accords with what is to be expected from an engine of this sort. I therefore give my testimony to the general accuracy of the figures in the paper.

Wing Commander Cave-Browne-Cave: The author claims that the consumption of a compression-ignition engine will be considerably better than that of a petrol engine. His work has been with a single-cylinder engine, but there is always a considerable difference between the results with a single-cylinder engine and those with a multi-cylinder engine in petrol engines on account of the irregular distribution between the cylinders. The work we have done with a four-cylinder compression-ignition engine confirms that this difference between single-cylinder and multi-cylinder engines is very much less than with the petrol engine. The economies which the author claims for the single-cylinder engine of the compression-ignition type are, therefore, likely to be improved upon in the multi-cylinder type.

Another very important point is that the economy increases as the power is reduced, while with petrol engines not only does it go very much the other way, but even the economy under test-bench conditions cannot be realised in flight, but it is so difficult to tell when the mixture strength is best suited to the conditions. On the other hand, the control of the compression-ignition engine is simply regulated by the supply of fuel. Therefore, in actual flight, I do not think there is any doubt that the economy will be superior to that of the petrol engine by more, rather than less, than the author indicates.

The specification to which we are purchasing oil for the projected airship flights, calls for a flash point of 210°F., which is a great deal higher than is asked for in even Navy boiler oil, and we can get it at no more than about £5 per ton. The author says that for working at altitude it will be necessary to

have some means of pre-heating the air. Is it not equally necessary to have some means of restoring atmospheric pressure, and some form of supercharger will at least also give the increase of temperature which is necessary, since, theoretically, if air at 10,000ft. is compressed adiabatically to ground pressure it will be at ground temperature, but actually it is at considerably higher than ground temperature. There is one disadvantage, limited to the use of engines in airships, in that it makes water recovery a great deal more difficult than with the petrol engine, since there is much greater excess air and more waste of water in saturating it, while the dirt and acid in the exhaust also give more trouble.

In speculating as to the possibilities of future development, any increase in the speed at which an engine will run satisfactorily depends apparently not on the increased speed of burning, but on the decreased hang-fire which takes place before ignition starts, and this would appear to be the point upon which research should be concentrated. The compression-ignition engine must, however, be heavier than the petrol engine owing to its high maximum pressure. If the inertia forces which the pistons absorb are increased, the peak will be taken off the maximum load. The optimum speed of an engine that normally runs at 1,000 revs. per minute is 1,400 revs. per minute, because that is the speed at which the difference between the maximum pressure and the inertia force on one stroke are equal to the inertia force on the idle stroke. Therefore, so far as forces on the moving parts are concerned, it is well worth while increasing the speed. There is the most objectionable alternative of making the piston heavier. I would like to emphasise the extreme importance of great care in making jets. It is very well worth while drilling the sprayer caps with the utmost care and adjusting the length of the holes to make it certain that they are exactly what they are intended to be, and calibrating each individual hole. Until we tried carefully made square caps against caps made ostensibly to the same drawing but with much less care, we did not realise its importance.

Most single-cylinder engine research has not been done with open exhaust, but I suggest that the appearance of the exhaust is as useful as it has always been found with the petrol engine. With our experimental four-cylinder engine at Cardington, we found that the pressure of the gases leaving the exhaust was considerably lower than the pressure in the petrol engine exhaust, and therefore the noise occasioned comparatively little discomfort, while the gases can be taken away with a fan. It is well worth doing for the assistance given by the appearance of the exhaust, particularly with multi-cylinder engines.

Mr. L. J. Le Mesurier: The author has omitted one problem which is peculiar to the mechanical-injection engine, and that is the difficulty of getting such an engine to run satisfactorily at light load due to the carbonisation of the atomising nozzle and consequent faulty combustion. Perhaps this condition is not of very great importance in an aero engine, though I imagine it is worth consideration, but in the case of the other uses of this type of engine to which I have referred, light-load running is very often of great importance.

I agree that the form of injection chosen for the experimental engine in which the fuel valve is operated by a cam, gives the best possible control of oil injection, but I do not think it is one which is likely to be adopted in an aero engine or any other type of high-speed oil engine, as it is too complicated and difficult. Furthermore, the type of injection in which an ordinary pump is controlled either by a spill valve or the variable stroke of the pump, is giving excellent results at high speeds in many types of existing engines, such as the M.A.N., the Bolinder and the Benz; all these engines have a simple pump and an automatically operated injection valve, so that it might be well, if research work is being continued, that it should be devoted to this simpler type of injection.

I agree as to the need of great accuracy in workmanship in the atomising nozzle; in fact, I think that the atomiser holes should be drilled from the inside of the nozzle and not from the outside, as in the nozzle illustrated, since it is the shape of the hole on the inside of the nozzle that is most important, and a burr or any irregularity in that part of the nozzle is apt to give curious and erratic results. I also think that the nozzle should be cooled if possible, *i.e.*, it should be coupled up to some part of the fuel valve which is water-cooled. I am glad the author finds the ordinary plain hole is the best type of nozzle, as various kinds of fancy slots have been tried without showing any advantage over a plain hole.

It is of interest to note that while with this engine which developed, roughly, 90 b.h.p. at 1,200 revs. per minute, five holes, 0.0145in. diameter, were used, in the slow-speed engine with which Professor Hawkes was experimenting, and which gives 100 b.h.p. at 380 revs. per minute, five holes are also used, and these are 0.016in. diameter. It seems rather remarkable that in two such very different types of engines it should have been found that approximately the same size of holes gave the best results. The author did not indicate what the mechanical condition of the engine was or for how long the various tests were run, and I should like to ask if there was any tendency to over-heating of the pistons or sticking of the piston rings, and what was the condition of the exhaust, etc.? I notice that the indicated pressures were calculated by taking the brake mean pressure and adding to that the power required to motor the engine, but this makes the indicated pressure too low, because the friction when motoring is far less than when the engine is running under power, due principally to pressure on the piston rings when under load.

In conclusion, I would like to say that I agree with the author that the two-stroke engine is a very promising proposition. The particular point mentioned by Wing-Commander Cave-Browne-Cave about being able to keep the air warm at high altitudes may in a two-stroke engine be overcome by introducing a turbo-blower for scavenge purposes together with some system of exhaust-heating the air before admission to the cylinder.

Mr. A. F. EVANS: The information in the paper will be a surprise to many people who, in the past, have said that an engine of this kind is an utter impossibility, and that brake mean effective pressures of over 90lb. would never be attained. I should like to know if any endurance tests were carried out, and, if so, with what results. When supercharging with a petrol engine, there are certain difficulties in connection with the heating of the air, but I assume that with the Diesel engine these difficulties mostly disappear; for one thing, the supercharger can be run at constant delivery and the power varied as required by the fuel, which is hardly the case with a petrol engine. The large engine is obviously for airship work, but it is not easy to see how the revolutions can be increased to something like those of the petrol engine and the dimensions of the cylinder decreased. It is one thing to get these results from a ten-inch cylinder at 1,000 revs. per minute, but we must look for the same result from a three-inch cylinder at 2,000 revs. per minute, and I cannot see how this particular fuel-valve system can be operated with a sufficient degree of accuracy to supply the fuel to an engine of these dimensions.

In connection with the experiments in the United States which resulted in a penetration of 5in. with a plain jet, I should very much like to know how much dribble there was at the closing of the jet, because that is where most of the trouble occurs. Dribble causes carbon deposits, and if this can be eliminated most of the trouble will be overcome.

Major B. C. CARTER: When this work was put in hand some years ago, it was found that piston speeds were much below those required for any possible weight/power ratio for aircraft purposes, and that fuel consumptions

were too high at the highest speeds then attained. Further, at these higher speeds the brake mean effective pressures were low. One big doubt in those days also was the possibility of getting sufficiently rapid combustion, and this led the author to try all manner of variations of the soft spray—because there was a feeling that the hard spray would not burn at a sufficient rate. When the change was made to the hard spray, however, using a five-hole nozzle, there was at once a great improvement—the brake mean effective pressure went up from 80 to 113lb. per sq. inch.

With regard to the movement of air relative to the fuel, where there is a dished piston, the compression ratio is different for different parts of the piston, and as the piston approaches the top dead-centre there is a definite in-flow of air to the centre past the jets; as the piston recedes again, there must be an out-flow. I do not know how important that effect is, or how much it contributed to the present results. The piston crown of the unit is of curious form on account of the circumference being cut away in places to give sufficient clearance for the valves, but notwithstanding this there must be an airflow inwards and outwards as the piston approaches and recedes from dead-centre. That flow is not associated with any centrifugal force tending to whirl the fuel on to the cylinder walls. It seems to me that there is scope for more knowledge of what does happen to air in a cylinder. It depends upon design whether there is a swirl or a general turbulence or possibly vortex rings formed. It should be rather difficult to penetrate a vortex ring by a spray. It is possible that the in-flow and out-flow of air at top dead-centre has some part in producing the strange " kinks " in the curves of Figs. 9 and 10.

In the experiments described by the author, attention has been directed towards obtaining good economy at high engine speeds simultaneously with high brake mean effective pressures and moderate maximum pressures. Although it is important to get this combination, there are conditions of flight under which power is much more important than fuel economy—as, for example, when taking off in a seaplane.

By restricting the fuel per cycle so as to leave 30 per cent of the air unburnt, the experiments described were much simplified and doubtless many troubles were obviated, but it would appear that the question of the amount of extra power available for short periods regardless of fuel consumption should not be overlooked. The question is what extra power can be obtained, with a given airscrew fitted, by injecting sufficient fuel to burn all, or practically all, the air? It is true that the mean temperature of the cycle will be higher and the heat evolved will not be converted into work so efficiently owing to the greater departure from Air Standard; also with the injection so timed as to prevent the maximum permissible pressures from being exceeded there will be a greater tendency for combustion to continue during the expansion stroke with correspondingly less efficient conversion of heat into work, and higher exhaust pressures and temperature. Any increase in brake mean effective pressure will cause an increase in engine speed, and the extra power available may be quite appreciable notwithstanding the points mentioned. If, by burning the 30 per cent. excess air, a power increase of, say, 15 per cent. may be obtained in emergencies, without excessive pressure, the virtual weight/power ratio of the engine should be correspondingly less for some installations at least.

I should welcome the author's opinion as to the extra brake mean effective pressure that should be obtainable for short periods with a unit such as the 20.T. without increasing the maximum pressure but regardless of fuel consumption. In actual practice some increase of maximum pressure should be permissible, as engines need to be designed to withstand fatigue loadings and should withstand appreciably increased loadings for short periods without failure resulting.

Mr. W. A. WHATMOUGH: I should like to ask, from a combustion point

of view, if there is any particular reason why super-efficiency is obtainable by compression-ignition of a charge containing excess air. The attempt to subdivide fuel by spraying it through a definite sized orifice into a highly compressed gas, in other words, to rely upon fuel penetration to induce molecular combustion, must call for a delicate balance between fuel pressure and cylinder compression. I can quite follow that adjustment is made for a given engine speed and a particular compression, but it means pump pressure and compression resistance are designed to fit a particular set of orifices. I should like to ask if that state of affairs will hold at altitudes. Is there any definite suggestion that supercharging will be necessary to restore the optimum value as at earth level? So far as I can see the compression-ignition engine is definitely handicapped as regards that flexibility which is the most desirable characteristic in petrol engine practice. There can be but little margin for favourable fuel penetration when this depends upon the shape and size of a spraying orifice. This is bad enough in ordinary carburation, but I think carbonisation must be a great deal worse in compression-ignition engines. I am particularly interested in combustion with excess air as this must be localised burning. So far as I can interpret this, there must be decided stratification with combustion around the fuel spray. The heat of combustion is then transmitted by admixture of inflamed gases to excess air, the extra useful work being derived from prevention of heat loss to the walls and exhaust.

Wing-Commander G. B. HYNES: The majority of speakers have stressed the aeronautical side of the work, but this is only a relatively small part of the field opened up by such experiments. I think that a successful lorry or bus engine of this type would offer commercially much greater attractions and inducements than an aircraft engine at the moment. I do not want people to think that because we have done this work at Farnborough with that type of injection we hold any special brief for the mechanically-operated valve. It was selected as giving the most accurate control of the variables because this work was primarily a research. It was not directed to producing a commercial unit, and when the work was started a great many people who were in a good position to know were very pessimistic as to the chances of success, and I think one of the outstanding merits of the work has been that it has shown that it is possible to do certain things. Although this information has been published after a considerable lapse of time, it has, I think, already acted both as an encouragement and a spur to other people working on these lines in an endeavour to push up their performances and enabled us to regard our results as a sort of standard of reference.

Mr. G. E. WINDELER: I feel that this particular type of prime mover is essential to reliable, economical and safe performances in long-distance aeronautical work. Safety is assured by the use of the high flash-point fuel, and economy by the low fuel consumption. Reliability will depend probably on the particular designs and the nature of research in getting at the correct form of this prime mover.

The fuel figures are reasonable, and are consistent with the best land practice. With a certain 100 b.h.p. per cylinder engine working at 250 revs. per minute the fuel consumption was:—

10 per cent. overload	0.378lb.	per b.h.p.	per hour.
Full load	0.38	,,	,,
Three-quarter load	0.38	,,	,,

The very straight line curve between these ranges of load is a very important factor in this type of prime mover, because it bears out the author's promise of economies and saving in weight over long flights. I think that as development goes on it will be found that this type of engine will use a very large range of fuel oil without the necessity for adjustment of any consequence, and I imagine

that ultimately the engines used in submarines and aircraft will both use the same fuel. This would be a great advantage, in so much that our commercial oil stations throughout the Empire would be available for both in times of war.

This particular form of engine will, however, be more expensive to build, and for that reason it will be necessary to diagnose very carefully and eliminate the difficulties met with so that standardisation can be arrived at as soon as possible. In any case the elimination of the ignition gear will be worth while. In regard to the effect of lubricating oil consumption on the fuel consumption, I can state definitely that the figures obtained by the author are good standard figures—at least comparable with those we obtain at Stockport with which guaranteed lubricating oil consumptions are given.

I can confirm Wing-Commander Cave-Browne-Cave's remarks as to the improved results from the multi-cylinder engine over those from the single-cylinder engine. The mechanical efficiency is slightly improved, probably due to the combined inertia effect of the moving parts. As to the effect of altitude on the compression ratio, we have engines working out in Mexico at 9,800ft. altitude without the necessity for making any variation in the compression spaces or pre-heating the air. The engines will not, of course, give their full power in these circumstances.

I quite agree with the author that the two-stroke engine offers the most promising field. There is, firstly, its simplicity owing to the fewness of parts, and, secondly, it has been proved that two-stroke engines can be made equally as light as four-stroke engines. There is the further possibility of the double-acting two-stroke engine.

I think the form of fuel valve adopted by the author is on the right lines. The automatic valve is attractive and has the charm of simplicity, but it has the disadvantage that there is a serious time lag, so that the time of admission of the fuel into the cylinder is uncertain, which is not the case with the mechanically-operated valve. I am of the opinion that the air-injection engine beats any of the others; as yet nobody has shown me any better results under ordinary working conditions than those obtained at Stockport and elsewhere, and I am sure that a very satisfactory air-injection engine could be evolved without any of the complications that are assumed to exist in this form of high-compression engine.

Ft.-Lt. R. E. ALLEN: Could the author tell us if there has been any development of the Peugeot-Tartrais engine, which was an attempt to solve the problem of the Diesel engine for automobile work? I should also like to ask if the author regards air cooling as entirely out of the question.

Mr. W. A. GREEN: A good criterion of the possibilities of any particular engine from the power/weight point of view is provided by multiplying the brake mean pressure by the piston speed. Taking this figure for the engine described by the author, we get the value 221,000. This may be compared with the figures for two engines of somewhat similar size, the Beardmore Diesel locomotive engine giving 93,000, and, secondly, the M.A.N. lorry engine giving 107,000.

The figure for the author's engine is thus more than twice that of either of the others, a truly remarkable achievement.

There are, of course, existing commercial compression-ignition engines with cylinders of this size which would be rated commercially at about 20 b.h.p., but this would be on a fuel oil of from 0.90 to 0.95 sp. gr.

The author classifies injection systems under three headings, and I wish to put in a word for the second class, very aptly described by him as " jerk " injection.

Apart from the results now described, the jerk system has given results at least as good as those of other systems, the commercial ratings of either type

being of the order of 90 to 100lb. per sq. inch indicated mean pressure with fuel consumptions of 0.40lb. per brake horse-power per hour, the jerk engines using so-called crude oil and the other type using shale oil.

Further than this, I have myself obtained indicated mean pressures from the jerk engine of 120lb. per sq. inch with a clear exhaust—this from a commercial engine without any alterations whatever. The engine showed no signs of distress, but the test being an unauthorised one was only of a few minutes' duration.

The author condemns jerk injection on account of the low injection pressure, but this can be adjusted as desired, and can be as high as that used in the other system. With the jerk system the atomiser is of the differential needle type in which no fuel can pass the needle seat until its pressure has reached a predetermined value. As soon as the needle lifts the full unthrottled pressure of the fuel is available at the spraying nozzle. Should the delivery of fuel from the pump be too slow to maintain the designed spraying pressure at the nozzle, the needle returns to its seat with a snap. There can be no slow injection, and there is, in practice, absolutely no dribbling.

So far as I know, all engines working on the jerk system use some device to produce turbulence in the combustion chamber—most frequently a " neck " or " choke " between the combustion chamber and cylinder. In other words, the method of working is to make a fuel spray in the most convenient place and bring the air to it. The Vickers system, on the other hand, is to try to fill the combustion space with fuel spray. It seems reasonable to suppose that a better spray can be produced in the former system where the spraying apparatus is not restricted by the necessities imposed by the other.

The difficulty with the jerk system is so to design the combustion chamber as to bring all the charge of air within reach of the spray. A critical examination of the more usual arrangements will show that a considerable percentage of the air can never reach this oil spray at all. Moreover, the smaller the engine, the larger does this percentage of inaccessible air tend to become.

The author laid some stress on the question of maximum cylinder pressures as bearing on the power/weight ratio. I would suggest that as regards strength of parts the compression pressure is a better criterion, since any compression-ignition engine must be designed to withstand safely a pressure in the cylinder of about three times the compression pressure, regardless of the maximum working pressure. This latter, therefore, only affects questions of bearing areas and lubrication.

This brings out another difficulty that is likely to arise with small cylinders, whatever the injection system used. The compression pressures necessary to ensure certain starting are likely to be higher with the smaller cylinders on account of the greater cooling effect of the walls, and this will necessitate an even heavier construction than in the case of the larger engines. In this connection it would be of great interest to know what were the compression pressures obtained by the author with various compression ratios used.

Mr. H. V. STEAD (*Communicated*): The subject matter of the paper is admittedly a little out of date, and it is now generally recognised that an engine can be produced to give a good mean pressure and a good fuel consumption at high outputs. The problems to be solved now lie in other directions, of which the author has said nothing. One of the first of these is the ability to produce a successful small cylinder. The size of cylinder used in these tests (8 in. by 11 in.) is far above anything required in the automobile, agricultural and similar industries, and in most aeronautical work. The difficulties of reducing the cylinder size and still retaining good results are greater than the difficulties of obtaining very high mean pressures on an 8 in. cylinder.

The flexibility of the new oil engine is a point to which too much attention cannot be paid, and yet the author says nothing as to the ability of his engine to idle at a slow speed. In this connection it should be remembered that the arrangement of fuel nozzle, etc., which gives best results at high mean pressures may not give the best all-round results under commercial conditions. The difficulty of getting an injection system which will avoid dribbling at slow speeds and low powers and maintain good combustion under these conditions is very real. Failure to meet these conditions leads to a whole train of troubles. The nozzles carbonise and fuel oil passes down into the crankcase and contaminates the lubricating oil. Can the author tell us what has been his experience in this direction?

The firm with which I am associated, Messrs. M.A.N., have passed through all the stages connected with the difficulties mentioned, and a 4-cylinder model of the smallest cylinder size develops 45 b.h.p. normal output at 1,000 revs. per minute and has a bore and stroke of 115 mm. and 180 mm. respectively. No fuel valve, as such, is used at all, the nozzle (of simple design) forming the open end of the fuel pump discharge pipe.

Mr. A. H. R. Fedden (*Communicated*): The results which the author has obtained are of a very high standard, showing that a great deal of care and attention has been given to the development work, and it appears as if it will be very difficult to improve on the performance. I agree that the successful development of the high-speed compression-ignition engine should have a great future in the aeronautical field.

The main problem connected with this type of engine is certainly in the fuel injection system. The mechanical solid injection does get close to the ideal conditions, as far as fuel-valve control and constant injection pressure are concerned, and it is a great pity that this system is more or less confined to straight engines with overhead camshafts or push-rod mechanisms when cylinder expansion can be neglected. In attempting to apply mechanically-operated injection valves to radial engines the problem becomes very complicated, and it seems doubtful whether it is possible to arrive at a satisfactory solution.

Does the author agree that fitting a supercharger to a main engine should overcome the necessity of pre-heating the air at altitude?

How much cooler, from a fire prevention point of view, does the author think the exhaust piping on a Diesel aircraft engine would be as compared with a petrol engine?

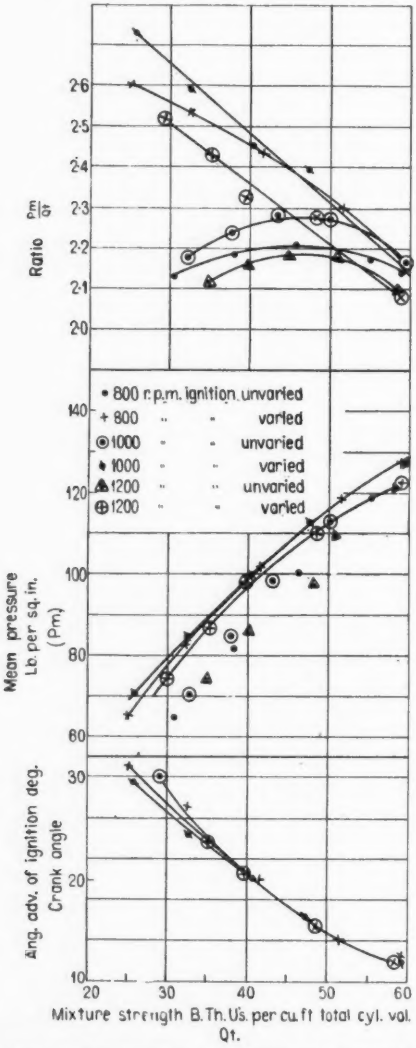
There is still scope for research work at higher speeds on smaller cylinders with efficient combustion, and the problem of starting up from cold without resorting to the use of petrol or electric methods has yet to be solved. Any comments as to how to start a Diesel aircraft engine would be interesting.

Mr. W. A. Tookey (*Communicated*): In Fig. 14, which consists of three sections, the angle of ignition advance, when this has been varied, is plotted in the lower section. The indicated mean effective pressure is plotted in the centre section and the Tookey factor of (indicated M.E.P./mixture strength) is plotted in the upper section.

Referring to the latter, it will be noticed how, when the ignition timing is unvaried, the resulting curve is very flat, whilst when the ignition setting is correlated to mixture strength the ratios between mean pressure and mixture strength increase directly with weakening of the mixture and advancement of the spark. The effect of speed is clearly indicated as giving higher efficiency in both instances, and from experiments reported by Sulzer before the Institution of Naval Architects some time ago, it would appear that one explanation of this increased efficiency might be the greater number of piston reciprocations and the undoubted additional cooling effect consequent thereon by the rubbing action of the piston rings against the cool cylinder walls.

It will be obvious from the central section of Fig. 14 that when mixture strength is taken into account there is no peculiar characteristic of the efficiency curves such as indicated in Figs. 9 and 10 of the paper. Indeed, it would appear that the " peculiar kink " to which the author refers is due to the manner in which the mean curves were fitted to the plotted points.

In my remarks in the discussion on the paper I intimated that in my opinion the indicated thermal efficiency complied with expectations formed with a know-

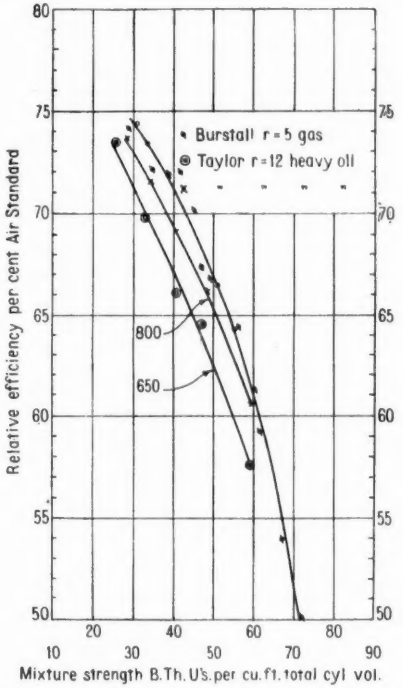


[By the courtesy of the Institution of Automobile Engineers.

FIG. 14.

ledge of tests made from other internal combustion engines, and in Fig. 15 I show how some of the author's results compare with the results of Dr. A. F. Burstall in his paper " Experiments on the High-Speed Gas Engine."* I have for purposes of presentation shown Burstall's results for a speed of 1,000 revs. per minute and for the author's results I have also taken two sets of experiments at 1,000 revs. per minute, one with 650 and one with 800 lb. initial pressure.

It will be seen that despite the differences between the methods of determining the calorific value of town gas and of heavy oil, the results are closely



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 15.

comparable with each other when compared with the air standard on a basis of mixture strength. It will also be seen that again there is no " peculiar kink " to be explained, the result of each set of experiments falling on its own curve with satisfactory alignment.

It is necessary for me to explain that the computation of mixture strength as used in this communication is based on the number of heat units contained in a cu. ft. of piston displacement volume plus clearance volume.

As an example, in line 1 of Table III. the indicated thermal efficiency is given as 36.5 per cent., and from this the mixture strength QT is:—

$$Qt = \frac{0.1852 \times \text{I.M.E.P.} \times r - 1}{\text{Ind. thermal effcy.} \times r} = \frac{0.1852 \times 127 \times 11}{0.365 \times 12} = 59 \text{ B.Th.Us. per cu. ft.}$$

* See Proc. I.A.E., Vol. XIX., p. 620.

Reply to Discussion

The Master of Sempill mentioned the possibility of longer flights being carried out with the compression-ignition engine, and I feel that it is in this respect that this class of engine will at first become most useful.

In order that we may thoroughly appreciate this point, let us take an example of a long-distance machine equipped with a petrol engine of 500 h.p. carrying petrol for a flight of 40 hours, say, 4,000 miles. Let us assume the engine to weigh 1,000 lb. and to develop 400 h.p. during the flight with a fuel consumption of 0.6 lb. per brake horse-power per hour. The fuel to be carried will weigh 9,600 lb., the total weight of engine and fuel being 10,600 lb. A compression-ignition engine of the same power will probably weigh 1,500 lb., which will leave us with an allowable load of 9,100 lb. of fuel. The consumption of the engine when throttled to 400 h.p. will be about 0.38 lb. per brake horse-power per hour, which will allow the flight to proceed for almost 60 hours. That is to say, the duration of flight has been increased 50 per cent. This is the possibility opened up by the use of these engines, and in my comparisons I have not quoted outside figures.

The difficulty of extensive light-load running has been referred to, and I appreciate that there might be difficulty, but the light-load running required in an aviation engine is such that no trouble need be anticipated in this respect. This engine idles perfectly at 250 revs. per minute although it is a single cylinder engine.

Doubt has been expressed as regards the likelihood of the adoption of the mechanically-operated fuel valve. These doubts may be well founded, and if simpler forms of injection system will produce equivalent results they will be adopted, but this has yet to be demonstrated. A considerable amount of courage would be required to predict that anything in the mechanical line cannot be done; progress takes place continuously, and probably someone will evolve a method of accomplishing this valve operation satisfactorily if the results are worth it; if they are not, the system will be dropped. There is no doubt that the simple form of injection system will be most favourably received so long as the results produced by it fulfil the conditions demanded for the particular service for which the engine is required.

Several examples have been quoted of high-speed engines using " jerk " injection, but I think it will be agreed that the brake mean effective pressure produced by these engines does not come within the range dealt with in my paper, and so would not be suitable for aircraft purposes. I considered only those systems which produce brake mean effective pressures in excess of 100 lb. per sq. in., and there are very few commercial engines running with anything like this figure regularly. Most systems of injection will produce good results at low mean pressures; it is only in the higher ranges that the difficulties commence, *i.e.*, if a curve be drawn of fuel consumption on a mean pressure basis, the inferior injection system will compare favourably up to a moderate mean effective pressure, say, 90 lb. per sq. in., but, if pushed further, a rapid divergence of the curves takes place in favour of the superior injection system.

Owing to the definite characteristics possessed by fuel sprays which are not easily departed from, it may be easier to bring the air to the fuel rather than convey the fuel to the air, but sight should not be lost of the extreme heat loss involved in some of these systems.

I do not condemn " jerk " injection, but have merely attempted to point out the various features associated with the different systems of injection when considered for high outputs.

It should be borne in mind that the testing out of different methods of injection is a very laborious business, and we are, as yet, only on the fringe of the subject in respect of high-speed engines.

I have always realised the need for accuracy in drilling the holes in the nozzles, and one man only in the R.A.E. has drilled all our nozzles, he being a very skilled instrument worker. He has indeed made several nozzles in the later stages which required no adjustment when calibrated with a head of petrol. Drilling the holes from the inside will be very difficult in many cases, and is of doubtful necessity if the burrs are carefully removed with a rose cutter after drilling. We have had no difficulty in repeating our results on different nozzles made ostensibly to the same dimensions.

I am afraid that owing to concentration on investigation of the different characteristics of the nozzles, etc., no attempt at any duration testing was made. The engine ran altogether approximately 700 hours, and at times for long periods without removal of the cylinder head, although no individual runs lasted for more than about five hours. When the cylinder head was removed for any reason, the quantity of carbon present could be described as normal for a petrol engine. No trouble was experienced due to piston rings sticking, and the exhaust valves were very much happier than those in any normal petrol aviation engine. In fact, our mechanical troubles were much fewer than I had expected.

There is no doubt that supercharging provides the solution of the problem of the compression-ignition engine working at altitude. Not only can the requisite temperature be obtained equivalent to ground conditions, but, if desired, a far higher temperature is available. Further, than that, I would prefer to make no further reference to supercharging.

As regards the difficulty of obtaining similar results in smaller cylinders at higher rates of revolution, I think it must be conceded that the difficulties to be met with will be greater, but we must carry on and overcome them as they arise.

Captain Irving has asked for the date of completion of the tests. The tests commenced in November, 1921, and the following June brake results in excess of 100 lb. per sq. in. mean effective pressure were obtained. The work then progressed, numerous combinations being investigated, and the engine finally completed the full series of tests towards the end of 1924. Various breakdowns contributed to the delay, although they were not of very serious import. One was due to defective design of the piston, the gudgeon-pin bosses giving way, and in making a new piston a lot of time was wasted. This and other things, such as the substitution of the improved fuel pump, took time, and the tests occupied approximately three years.

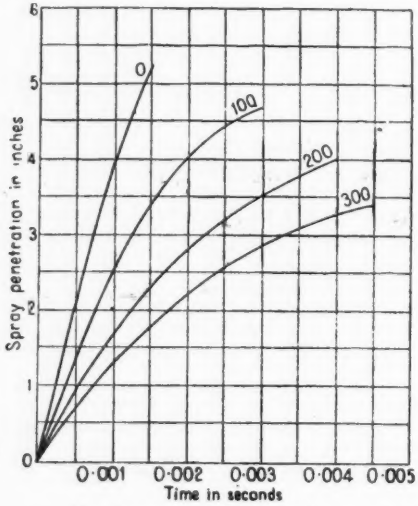
As regards the relationship between the maximum cylinder pressure and the engine speed, it will be appreciated that the higher the speed the shorter will be the time available between commencement of injection and the completion of combustion. At higher speeds it is necessary, therefore, to obtain a higher difference in temperature between the air (or products of combustion after the fuel has commenced to burn) and the unburnt fuel globules if the same quantity of fuel is to be burnt at a greater rate. In order to obtain a higher difference in temperature, higher pressures are necessitated, which are created by injecting the fuel earlier in the cycle.

I think Captain Irving is mistaken when he says that the American tests conclusively proved that penetration is independent of the pressure into which the fuel is injected, but that he will find that the rate of penetration is affected considerably by the density of the medium into which the spray is injected. Even now I can visualise various curves which slope more and more as the pressure increases. Miller and Beardsley, of the Langley Memorial Aeronautical Laboratory, U.S.A., show that the spray penetration is affected considerably by the chamber or cylinder pressure. Figs. 16 and 17, extracted from their report,* illustrate this clearly.

* N.A.C.A. Report, No. 222. "Spray Penetration with a Simple Fuel Injection Nozzle."

There is no difficulty in getting an engine to run at 2,000 revs. per minute; an engine can be run at any speed until it breaks, but we are concerned with the results produced at these high speeds, and the performance must be high to merit consideration for aircraft.

From Captain Irving's description, the modified four-stroke petrol engine burning heavy fuel would appear to be handicapped by the detonation characteristics of the fuel used, and, owing to the low compression ratio required, would not have a performance equal to aircraft requirements. The economy of



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 16.

Effect of chamber pressure on penetration.
Fuel pressure, 2,000 lb. per sq. in.
Chamber pressure, 0 to 300 lb. per sq. in. gauge.

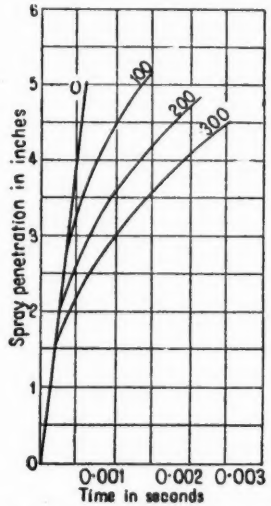
the compression-ignition engine is obtained not merely by virtue of the high compression ratio used; the excess air present, particularly at reduced load, is a contributing factor, giving a lower temperature cycle and reduced heat loss. Thus, the high-compression petrol engine using expensive doped fuels does not become a substitute for the compression-ignition engine.

With regard to lubricating oil consumption, we had an engine, unfortunately, of the wet-sump type with which we could not make precise measurements, but I can only say that the amount of oil added to the engine throughout the investigation was noted to be extremely small, *i.e.* several weeks might elapse before perhaps a gallon was added. This frequently proved to be too much, the connecting-rod lashing the oil up, and we got excess oil in the combustion chamber with heavy detonation and a considerable rise in mean effective pressure. It was necessary to stop the engine with the least possible delay, and the removal of half a gallon of oil effected a certain cure.

I thank Mr. Tookey for his confirmation of the accuracy of my results, and am most interested in his analyses of the figures given. In this connection there are just two points: first, it is not clear from the upper portion of Fig. 14 that the efficiency is higher at the higher speeds, the curves at 1,200 revs. per

minute being the lowest and those at 1,000 revs. per minute the highest; secondly, I agree that if the tabulated results are plotted, smooth curves result, but the curves plotted from many more observations than those tabulated produced the kink referred to most consistently and could not be ignored. The points deviating from the smooth curve were usually between full power and 80 per cent. of full power.

I agree with Wing Commander Cave-Browne-Cave that, compared with petrol engines, compression-ignition engines will more closely approach the single-cylinder results owing to the difficulties of distribution met with in the former. Uneven distribution of fuel to the various cylinders of a compression-ignition engine, if encountered, is reflected in the power output to a very large



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 17.

Effect of chamber pressure on penetration.
Fuel pressure, 8,000 lb. per sq. in.
Chamber pressure, 0 to 300 lb. per sq. in. gauge.

extent, whereas, in the petrol engine, enriching certain cylinders does not result in an increase of power (it may be a decrease) owing to the range of mixture strength which gives constant power; on the other hand, certain cylinders receiving weak mixture are liable to give trouble with overheated exhaust valves and sparking plugs.

With regard to the cost of oil, I think that if an aviation petrol engine is deserving of the best petrol that can be procured, an aviation engine using heavy oil is also deserving of the best of the heavy oils if reliability is to be obtained. If we tried to use cheap petrol in the modern aviation engine I shudder to think of the result. A cheap fuel oil should not be used, if its cheapness is due to a heavy content of dirt and asphalt.

Water recovery for airship work is undoubtedly very difficult with compression-ignition engines owing to the amount of excess air present in the cylinder which absorbs moisture which cannot be recovered easily.

Reference was made to the possibility of offsetting the forces due to the high maximum cylinder pressures with the increased inertia forces due to running at a higher speed, but I think that, except in the radial engine, increase of speed can only be applied reasonably in the two-stroke engine, otherwise the increased inertia forces on the exhaust stroke of a four-stroke engine would be encountered and would lead to high loadings.

To run with open exhaust is, no doubt, very desirable, and a lot can be learnt from it, and though smoke is the chief thing which is to be seen during experimental work, as Wing-Commander Cave-Browne-Cave says, it can be taken away with the fans.

Mr. Evans has referred to the results obtained and suggested that they would set people thinking. If that is all the tests do, they will have been warranted and we shall have achieved our object.

Major Carter has mentioned the uncertainty of the project at the commencement. When we first started we were very dubious about obtaining any worthwhile results, and I have been told that in the early days of Diesel engines one person who was connected with them actually said it was impossible to run a Diesel engine at 400 rev. per minute, but we have gone a long way since then.

I do not think the brake mean effective pressure will be increased more than 10 per cent. if an unlimited quantity of fuel be injected and the maximum pressure remains unaltered. With a fixed airscrew the 15 per cent. increase of power referred to by Major Carter might be obtained.

Mr. Whatmough has expressed an academic view of the conditions required if optimum results are to be obtained from a fuel spray, and, academically, he is probably right. In practice, however, the spraying orifices are chosen to give the best all-round results in accordance with the duty for which the engine is required. As regards the aviation engine, we are only concerned with good results at normal speed, maximum speed, and some speed slightly below normal, and if the engine is controllable at other speeds it serves the purpose; this engine is remarkably controllable.

I agree with Mr. Whatmough's interpretation of the gain in efficiency obtained when excess air is present.

The effect of high altitude conditions on the spray characteristics has yet to be determined accurately, but compression-ignition engines have been working at altitudes quite satisfactorily without change of adjustments as mentioned by Mr. Windeler. The results obtained from the slow-speed engines mentioned by him are considerably better than those obtained at the time I was connected with his firm, but I think he will agree with me that these consumptions are obtained at lower brake mean pressures than 100lb. per sq. inch. He also referred to the possibility of making a compressor work at high speed; whilst that may be so, the valving becomes very difficult, and I should imagine the mechanically-operated valves would have to be used to obtain a good volumetric efficiency. I doubt whether the improved performance of the air-injection engine would compensate for the added weight of the air compressor.

I cannot answer Ft.-Lt. Allen's question regarding the Peugeot-Tartrais engine. There is no inherent difficulty in using air-cooled cylinders on the compression-ignition cycle, and such engines will, no doubt, be used in aircraft quite commonly in the future.

Mr. Green has compared the figures quoted with those obtained from other engines on the basis of brake mean effective pressure by piston speed, which gives a rough idea of the relative merits, but for aviation purposes it is necessary to introduce into the denominator some function of the maximum cylinder pressure, which affects the structural weight of the engine, and of the fuel consumption,

which affects the total weight of the aircraft in varying degree according to the length of flight contemplated.

I do not agree that the compression-pressure is a better criterion than the maximum cylinder pressure with reference to the requisite strength of parts. Relief valves can be provided to deal with any unusually high pressures which may arise inadvertently; certain engines with individual detachable cylinder heads blow at the joints without consequential damage when high pressures occur, and this forms an admirable relief-valve. The compression-pressure at a ratio of 12:1 was in the region of 400lb. sq. in.

Mr. H. V. Stead asks for my experience in connection with contamination of the lubricating oil. Owing to the good combustion obtained on the unit no appreciable contamination of the lubricating oil by the fuel was noticed, although it is only fair to point out that no attempt was made to run the engine at low speeds for long periods, this not being a condition to be complied with in aviation engines.

Mr. Fedden has asked how much cooler the exhaust piping would be on a compression-ignition engine compared with a petrol engine. This is a difficult question to answer in absolute terms, but, with good combustion, a considerable reduction in temperature should be effected due to the higher expansion ratio. Inferior combustion will result in an increase of exhaust temperature, as also will any attempt to overload the engine. It is an important subject, however, and should be investigated when multi-cylinder engines become available for the purpose.

The starting problem provides a happy hunting ground for the inventor, but the following methods have been considered:—

(*a*) By means of a barring engine running on petrol which rotates the main engine sufficiently fast to enable it to run on the compression-ignition cycle.

(*b*) By means of an inertia starter in which a small flywheel is rotated at a high speed by hand through gearing, and the energy so stored imparted to the crankshaft by letting in a clutch. The engine is turned through a small number of revolutions, and, if the fuel system is thoroughly primed, there is no reason why a successful start should not be accomplished.

(*c*) By means of some form of gas starting using electric ignition.

(*d*) By combusting some substance such as cordite in a closed container and utilising the high-pressure products of combustion to turn the engine by means of a timed distributor.

I think there is a distinct future for inertia starters in this field, provided a hand-priming device for the fuel system is incorporated.

Major BEAUMONT (President, Institution of Automobile Engineers): We are grateful to the author for giving us a most interesting narrative of this piece of research work and of setting it forth in such a manner that we are able to understand how once more by a series of small stages, a great improvement has been secured. Most of us remember years ago the endeavours in connection with the Hornsby-Akroyd engine and probably there are many present who will remember the constant trouble through carbonisation of the injection aperture. Just as with the automobile engineer minute and painstaking attention to develop small details has effected wonderful improvement in power output and reliability, so here again with this particular form of engine we see the same course of events has been followed. I should like to express on your behalf a most hearty vote of thanks to the author and, at the same time, to our Chairman.

The paper was also read before the Manchester branches of the Institution of Automobile Engineers and the Royal Aeronautical Society. The following is the discussion at that meeting and Mr. Taylor's reply:—

Mr. WINDELER, in opening the discussion, said: I feel that many people will regard the working pressures at which the author has carried out these tests as quite unreasonable and unsafe. Years ago, however, people used to smile incredibly at the working pressures then suggested for the Diesel engine, *i.e.*, 480 to 500 lb. per sq. in. In the light of the progress that has been made, it seems as though within the next few years for high-duty engines we shall approach working pressures of 1,000 lb. per sq. in., which will be rendered possible by the extraordinarily high quality of materials available.

Some of the excellent practical points indicated by the author, such as the most suitable angle of the sprayer holes, the length of the passage through which the oil passes, and the best size of the hole to be used, should be of great assistance to those who are engaged on similar work. Another point of great value is that the tests were carried out on shale oil, as this fuel oil is obtained from Scotland and can be procured of a consistent quality.

The type of engine described would be high in cost of production, so that designers and research sections will have to be careful in their analysis of the troubles they experience in order to proceed on right lines and avoid the necessity for frequent alterations. The author mentioned the possibility of the two-stroke engine, but for high-speed engines there will have to be very considerable changes of view as to the type and lines to follow; anything in the nature of crankcase compression will be undesirable.

Mr. R. ONIONS: The author has only mentioned nozzles with holes, and I should like to ask what advantage, if any, holes have over slots. I would also ask him to give us a large view of the cam which operates the injection valves, showing how it opens and closes. A good deal depends upon whether it opens quickly or slowly; in the latter case there might be a dribble, and in the former there might be a sharp cut-off. I should also like to ask what advantage is to be gained if the air is introduced in a turbulent fashion, as is done in the case of gas engines to considerable advantage.

Mr. H. KEARSLEY: I should like to ask what are the possibilities of solid injection being applied to automobile engines. With a cylinder head of 8 in. diameter, is not the efficiency liable to be imperilled, due to the jet stream striking the cylinder walls before full atomisation takes place? I should also like to ask if the author has experimented with a conical hole, which would give a wider angle of fuel injection from each hole in the nozzle.

Mr. C. TURTLE: The author assumed an engine weighing 1 lb. per brake horse-power more than existing designs of petrol engines. Is this an accomplished fact, or merely an ideal?

Mr. A. T. J. KERSEY: A remarkable feature in connection with the engine is that satisfactory combustion was obtained with so low an air ratio as 1.3, or 30 per cent. excess air. I believe that with the larger slow-speed engines approximately 1.7 to 1.8 is about the best air ratio at which satisfactory combustion with the so-called solid injection has been obtained. Low air ratio gives a very high mean effective pressure and a corresponding reduction of weight per horse-power, with a corresponding increase in mechanical efficiency, as friction horse-power does not increase with the load. That so low an air ratio is practicable is probably due to the fact that penetration difficulties are far less with an engine of so small a size than with a larger cylinder. It is essential to have sufficient atomisation for quick combustion. At the same time the jet must travel sufficiently far to penetrate the air and become thoroughly mixed. The shorter the distance the jet has to travel the greater is the atomisation possible with a given

pressure. This is, at any rate, one of the explanations of the low air ratio which was possible, together with what was fairly complete combustion from the efficiency obtained. This possibly again explains why the result described has been obtained with the comparatively low injection pressure of 5,000 to 8,000 lb. per sq. in. as against the 10,000 to 15,000 which appears to be necessary in practice with large marine engines. I should like to ask how the injection pressure was measured. Naturally, attention was concentrated on the injection apparatus, as the other part of the engine was more or less orthodox.

From theoretical considerations, the discharge from an orifice in lb. per second is given by

$$W = 5.26c.A.\sqrt{p.s}$$

where c = coefficient of discharge of the orifice.
A = area of orifice (sq. in.).
p = difference of pressure producing flow (lb. per sq. in.).
s = specific gravity of fluid discharged.

Taking the data given in the paper, we obtain the following:—

$$\text{Oil per second (lb.)} = 0.00403c\sqrt{p}$$

where p is the difference between the injection pressure and the average pressure in the cylinder during injection. If D is the period of injection in degrees of crank angle, the time of injection is $D/6N$ sec., number of injections per hour $= 30N$, from which

$$\text{Actual weight of oil injected per hour} = 0.0201c.\sqrt{p.D}.$$

(This is independent of the speed of revolution if the injection pressure is constant.)

Consideration of the set of results at the end of Table IV. gives the weight of oil injected per hour as $0.45\sqrt{p_1 - 600}$, where p_1 is the injection pressure.

In the experiments of Mr. A. L. Bird,* it will be seen that one of the orifices corresponding most nearly to the orifice used by the author gave a coefficient of discharge of approximately 0.5, so that $0.01D = 0.45$ in this case, giving a period of injection of 45 degrees of crank angle. I would like to ask the author what was the actual angular period of injection. From the indicator diagrams, it would appear to be much less than I have suggested, which would seem to show that either the pressure as given was not the true average injection pressure, or the coefficient of discharge of the orifices must be higher than 0.5.

I imagine that the time lag from the beginning of the injection to the beginning of the rise of pressure must be extremely small. Professor Hawkes has given a curve showing how the time lag depends upon the original temperature at which the oil is injected. Mr. Bird† gave curves showing how the time lag depended upon the pressure and temperature. Unfortunately, those curves did not extend far enough to be applicable to the conditions of the present experiment. He gave the minimum time lag in that particular case as 0.022 sec. If the author had considered those results as final, he probably would never have started to design his engine, because 0.022 sec. would mean a considerable proportion of a revolution. Apparently, 12 degrees is considered sufficient to overcome the time lag at a speed of 1,200 revs. per minute. This is evidently due to the fact that there is exceedingly good atomisation, much better than was obtained in experiments with larger engines. It seems quite fair to assume that the finer the atomisation the smaller will be the time lag between the injection of the oil and the commencement of rise of pressure. I notice that the friction mean effective pressure for any particular speed was taken as a constant for the whole of the experiments, and I would like to ask if, after each experiment, the friction torque was measured under the same conditions as the experiment,

* See Proc. I. Mech. E., December, 1926.
† *Loc. cit.*

because there are many factors influencing the friction mean effective pressure, particularly the jacket temperature and the oil temperature, the latter being almost as important as the former. If the author has been able to keep his jacket temperatures and his oil temperatures so uniformly constant throughout the experiments as to be able to assume that the friction mean effective pressure was constant, he is entitled to very sincere congratulations. The friction mean effective pressure appears to follow very closely the law

$$p_f = 9.2 + 0.037.(N/100)^2.$$

This gives a value of 9.24 at 100 revs. per minute, which agrees very well with results from large engines running at this speed. The second term thus appears to represent the loss due to gas friction and inertia. The volumetric efficiency of the engine appears to be remarkably high in view of the high speeds attained. It is possible to estimate the volumetric efficiency from the particulars of the fuel and air ratio, and it works out at about 85 per cent. This is, again, practically constant for all loads at any particular speed—85 per cent. at 1,000 revs. per minute, with only a drop to about 83 per cent. at 1,200 revs. per minute.

Mr. A. Orton: The author refers to the method of actuating the fuel valve, particularly stressing the necessity for great rigidity in the driving mechanism. This is an excellent point to make, and the overhead camshaft system, by which all long levers, push rods, etc., are avoided, appears to be the best way of reducing "springiness" and consequent vibration of the working parts to a minimum. If it is remembered that the lift of the fuel valve is probably something in the order of only 0.01in., it will be realised that natural vibrations in the operating gear must not take place if regularity of the fuel charge is to be attained. Could the author tell us the actual lift of the fuel valve in this case?

With regard to the number of holes in the jet, it has often struck me in studying experiments on both large and small engines how often the best results are given by five holes. There seems to be something mysteriously useful about that number, and doubtless there is some natural explanation of the fact.

I have no doubt that the excellent fuel consumptions attained by the author were partly due to the high explosive pressure which he used, and I see no objection to its use so long as the engine was designed to suit. It might be of interest to mention that Junkers in Germany has built engines of the solid-injection type, having cylinders as small as 80 mm. diameter running at 1,000 to 1,500 revs. per minute in which similar high pressures between 800 and 900 lbs. per sq. in. were used. The fuel consumption published for one such engine, which was of the opposed-piston two-stroke type developing 45-65 b.h.p. at 1,000-1,500 revs. per minute and suitable for lorry work, was 174 grams (0.384 lb.) per brake horse-power per hour, at a brake mean pressure of 99 lbs. per sq. in. Has the author experimented with the type of injection used on these Junkers' engines, namely an injection pump of the "jerk" type connected by a very small diameter pipe to a valveless nozzle having a number of small spray holes? This system is also used by the M.A.N. Company for engines of both small and large sizes, and according to published accounts is giving good results. The advantage claimed is that the nozzle has no working parts and can be taken out of the cylinder head almost as easily as an ordinary sparking plug. There is nothing whatever to go wrong with it, except the possibility of its becoming choked.

With regard to turbulence, I should like to ask the author if he has done anything in the way of experimenting with rotational turbulence produced by screening a portion of the air inlet valve circumference, *i.e.*, making the air enter tangentially. A certain amount of work has been done on the Continent, notably by Hesselmann and by Krupp's, and I noticed recently a patent taken out by Ricardo for a similar arrangement. Apparently considerable advantage could be obtained by giving the air in the cylinder a circular movement which is just

sufficient to carry it, during the period of injection, through the sector included between adjacent sprays.

In conclusion, will the author tell us over what period the results were obtained, and also, from a practical point of view, what is the endurance capacity of the engine?

Mr. R. F. Taylor: Has the author considered the possibility of having an air-cooled engine of the type under consideration, and does he think there would be any trouble in connection with cooling? In Fig. 2 there is shown on the top of the cylinder head a rather large arrangement for holding the spring. Could this be done away with on an aero engine so as to reduce the frontal area? Further, is there any information available as to the cylinder and exhaust valve temperatures, which will probably be fairly high?

Mr. Begg: In connection with this fuel injection system, can the author say what are the advantages of the full reservoir system over the system which does not employ the reservoir?

Dr. Telford Petrie: As the result of work carried out some time ago I came to the conclusion that the ratio of the length of the nozzle hole to its diameter plays rather an important part in the general running of the engine as well as in the economy. There is distinct evidence of a vena contracta forming in the hole repeating the well-known experiments made on a larger scale in an hydraulic laboratory. The length of the hole has to be less than the portion where the vena contracta starts enlarging again, or else irregular consumptions will result. I should like to ask the author if he has had cases of nozzles with which he did not get consistent results in consumption. The results are bound to be inconsistent if half-a-dozen nozzles are run in the same engine if they happen to be critical, or approximately critical, lengths. It is interesting to learn that by working with much higher pressures than I used the author obtained much the same numerical results. In all my cases the maximum safe length of the hole to the diameter ratio was 2 : 1. I have come to the conclusion that if a perfectly free hand is given it is better to take a combustion chamber and build it round a series of sprays rather than to try and fill the combustion space with jets in various ways. It will be found that the combustion space shown in Fig. 2 fits the jets. This might be the reason why the five-jet nozzle was most favoured. Probably, with the disc shape of combustion chamber the same good results would not have been obtained.

Mr. J. Okill: The cylinder of the engine described in the paper is of fairly large dimensions, 8in. by 11in., and with smaller cylinders developing, say, 10 b.h.p. at 1,500 revs. per minute the difficulties in connection with the construction and maintenance of fuel-injection devices would be much greater than have been encountered in the engine described.

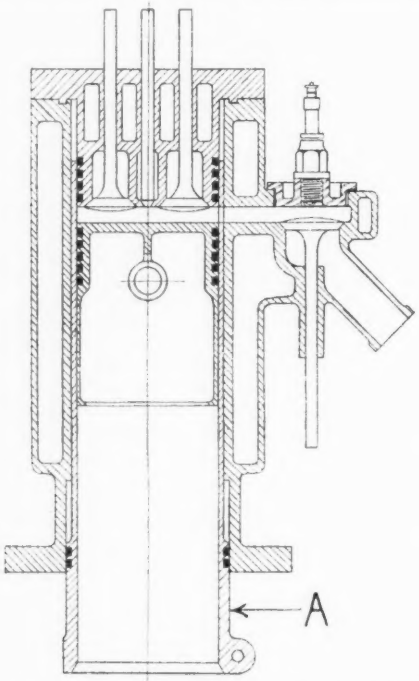
Assuming a fuel consumption of 0.5 lb. per brake horse-power per hour for a 10 b.h.p. four-stroke single-cylinder engine, the weight of fuel per charge at full load would be 0.0503 gramme, which is approximately the weight of three drops of paraffin oil. Such a small quantity calls for great accuracy on the part of the fuel pump and spraying system.

I have experienced some difficulty in obtaining directional accuracy in the discharge of liquids from small orifices, and should be glad to know whether the author has encountered a similar difficulty in the construction of the nozzles illustrated in the paper. How many drills were broken and what proportion of the nozzles have to be discarded due to inaccuracies in manufacture?

I should also like to ask what was the measured gauge compression-pressure with the volume ratio of 12 :1. Has any attempt been made to run the engine by direct injection of petrol instead of paraffin?

How is it proposed to start such an engine fitted in an aeroplane? It is not really necessary to start against the full compression-pressure provided that the volume ratio of compression is not reduced and that air is not allowed to escape from the cylinder during the compression stroke. Professor Watkinson's experiments have proved that it is possible to get ignitions in Diesel engine cylinders at a reduced compression-pressure by throttling the ingoing air until the compression-pressure does not exceed 200 lb. per sq. in.

In a paper* before the North of England Centre of this Institution, I proposed an engine which would operate on either the " Otto " or the " Compression-Ignition " cycle as desired. The design was intended for comparatively small



[*By the courtesy of the Institution of Automobile Engineers.*

FIG. 18.

cylinders, such as would be used on commercial-vehicle engines. Fig. 18 shows the cylinder with a cleanance volume suitable for operating on the " Otto " cycle. By raising the hand-operated sleeve (A), the side chamber containing the mixture admission valve and the sparking plug is cut off, the resulting clearance volume being that necessary to enable the engine to operate on the compression-ignition cycle. It was proposed to start the engine by hand cranking against the low compression-pressure and after running for a few minutes the cylinder would be hot and the engine mechanism would have sufficient momentum to enable a change-over to the compression-ignition cycle. It would probably only be necessary to fit one cylinder of a multi-cylinder engine with the alternative cycle device.

* See Proc. I. A. E., Vol. XVIII., Part II., p. 577.

Reply to Manchester Discussion

Mr. Windeler referred to the attitude of certain people towards the use of high working pressures in the cylinders, but too much fear has been entertained of a pressure of 1,000lb. per sq. in. in the past. According to the construction of the engine, there is no reason why such a pressure cannot be accommodated easily. I do not know of a case of the actual bursting of the combustion chamber of an aviation-engine cylinder, although the pressure is sometimes extremely high under pre-ignition conditions. This is one reason why it is possible to proceed with every confidence with the class of engine described. Such pressures occur daily in engine cylinders, but because people are not aware of their existence they do not worry about them. My experience is that the pressure cycle in a compression-ignition engine is far more regular than that in any engine running on the constant-volume basis.

Actually there is a wide range of fuel oils available, and the only provision to be made in the case of aircraft is to ensure that the oil will flow from the tanks to the engine at the low temperatures encountered at high altitudes. If a very viscous oil be used, the tanks will have to be heated. If heavy gravity oils can be obtained cheaply and their cleanliness maintained, there is no reason why they should not be used, but it would be madness to feed an aviation engine, which is very costly, with anything but a clean oil free from asphalt. I agree that crankcase compression will be undesirable in two-stroke aviation engines.

In reply to Mr. Onions, the slot type of nozzle gave poor results owing to insufficient penetration. The variations tried were merely those of size, and the best results obtained are quoted in the paper. Additionally, the hole type of nozzle is much easier to manufacture. The cam used is symmetrical with concave flanks and a small tip radius.

I have been restricted to the use of one unit in the experiments described, and have, therefore, no information on the effect of variation of the type of turbulence. The air swirl in this unit would be longitudinal in the cylinder, the path taken approximately an ellipse.

It is probable that difficulties will be encountered in obtaining good results on smaller cylinders, as mentioned by Mr. Kearsley, but progress will have to be made step by step. So far as can be judged from the published literature on the subject, the amount of experimental work done on this particular class of high-speed engine is, as yet, of a very meagre nature, but a growing interest is being taken which may have far-reaching results. Respecting the suggestion of the fuel jet striking the cylinder walls, only in one case was there an inferior performance with an increase of injection pressure, namely, with the six-hole nozzle, and this I ascribe to the reduced penetration with the smaller hole; I do not think it is a question of the jet striking the cylinder walls. I have not experimented with conical holes, and do not think such holes would lead to an improvement in results.

As regards the question of weight mentioned by Mr. Turtle, experienced designers have considered this matter and reached the conclusion that the figures referred to in the paper are quite within reach. Owing to the low weight required for an aircraft engine, the stressing of the various parts is more thoroughly investigated than is the case with any other prime mover within my knowledge, and by making a suitable allowance in respect of the parts requiring additional strength a very good estimate can be arrived at regarding the increase of weight.

Referring to the good results obtained with only 30 per cent. excess air in the cylinder, it is probably correct that a large number of commercial stationary engines, running at what is popularly known as full load, have excess air varying between 50 per cent. and 150 per cent., which gives a low mean effective pressure, as Mr. Kersey points out. In this connection there must be available mean

effective pressures of over 100 lb. per sq. in. before the aviation engine is at all in sight. Therefore, results given concerning the consumption of certain engines without the relative factors, such as maximum cylinder pressure and brake mean effective pressure, do not convey any information of use to aircraft engine designers. All three factors must be combined in estimating the relative performance.

The injection pressure was measured by means of an ordinary standard pressure gauge, and the figures given refer to the mean pressure during injection; the capacity is introduced merely to reduce the pressure fluctuations. As the atomisation is largely dependent on the injection pressure, any variation in this pressure during injection leads to a variation of atomisation; since it is important to maintain the atomisation as nearly constant as possible throughout injection, too large a capacity cannot be introduced except from the point of view of encumbrance and lag in control.

The angular period of injection varied slightly during the tests from 25·5 degrees to 28 degrees, but was in general 26 degrees.

The friction losses were measured by a swinging-field electric dynamometer whereby a mechanical and not an electrical measurement is made. The losses were assumed to be the same at the same speed throughout the tests, measurements of the friction horse-power being made but once, as the whole unit had to be transferred to another location for the purpose. The outlet water temperature was maintained between 70°C. and 80°C. throughout the test, but little control over the oil temperature was possible owing to the wet-sump system, although it was assumed that after a certain period of warming up it would become more or less stabilised. The actual volumetric efficiency measurements were 86 per cent. at 1,000 revs. per minute and 84.5 per cent. at 1,200 revs. per minute.

In reply to Mr. R. F. Taylor, there is no fundamental reason against the adoption of air cooling for this class of engine. The mean cycle temperature is lower, due mainly to the presence of excess air, and the exhaust valves being much cooler than those of a petrol engine owing to the higher expansion ratio. The deletion of the fuel valve spring might be effected by a pressure-balanced valve.

Dr. Telford Petrie has stressed the importance of the ratio of length to diameter of the holes in the nozzles. The best one came out at about 1.38, which result agrees very closely with tests made in the U.S.A. by Joachim and Beardsley.* I have not yet found any inconsistency of results which could be attributed to the nozzle. The best nozzle was checked by having another one made and tested; it yielded within 1 per cent. of the same results. The nozzles were made chiefly by one man, who progressively improved as time went on; the operation is one requiring a great deal of dexterity. With regard to the building of combustion chambers around jets instead of the reverse process, this might have to be done in the future with a system of injection possessing certain definite characteristics from which it is not easy to depart.

In reply to Mr. Orton, one effect of spring in the fuel valve operating gear with the design of valve used is to create a sudden increase of lift as soon as the valve is raised from the seat. The tip area becomes exposed to the fuel pressure, and the opening force is thereby considerably reduced; sudden elongation of the gear then occurs, giving rise to a very rapid admission of fuel. The lift of the valve is in the region of 0.018 in.

I have not carried out any experiments with the valveless type of nozzle, nor with rotational turbulence. Individual test runs were carried out in spells of from three to five hours, fuel consumption readings being taken at intervals over

* N.A.C.A. Report, No. 268. "Factors in the Design of Centrifugal Type Injection Valves for Oil Engines." W. F. Joachim and E. G. Beardsley.

a period of a few minutes. No attempt was made to carry out endurance tests, it being a research investigation; additionally, the design of the unit bore but little relation to that required in a full-scale aeronautical engine.

Referring to Mr. Okill's remarks, no difficulty has been experienced in obtaining holes drilled at the correct angle, a jig being used for the purpose. No record has been kept of the number of drills broken, but from memory the number of nozzles discarded for any reason does not exceed 20 per cent. and may be much less. I refer to all nozzles made experimentally and with large ranges of hole size, length, angle, etc. In drilling the holes a watchmaker's drill is used, operated by a foot switch, thus leaving both hands free for the work; considerable delicacy of touch is required and it is necessary to ensure that the drill is cutting all the time. A blunt drill will certainly break and thereby scrap the nozzle.

The compression pressure at a ratio of 12 : 1 is in the region of 400 lb. per sq. in. No attempt has been made to run with petrol as fuel.

As regards the method of starting, various schemes have been considered as mentioned in my reply on the London discussion.

PROCEEDINGS

FOURTH MEETING, SECOND HALF, 63RD SESSION

A meeting of the Royal Aeronautical Society was held in the rooms of the Royal Society of Arts, at 18, John Street, Adelphi, W.C.2, on Thursday, February 2nd, 1928, when Flight-Lieutenant R. E. H. Allen (of the Motor Transport Section of the Air Ministry) read a paper on "Ground Transport for an Air Organisation," which was illustrated by numerous lantern slides illustrating the various types of vehicle in use, and by cinematograph films showing the operation of such vehicles. Colonel the Master of Sempill (Chairman of the Society) presided.

The PRESIDENT, opening the proceedings, expressed the Society's indebtedness to the Air Ministry for having given Flight-Lieutenant Allen permission to prepare his paper and to show films and slides. Many people, he said, when speaking to him about the subject of the paper, had suggested that surely it was rather a dull subject, that there was really nothing in it, and that all the Air Force required was a few cars and lorries and vehicles for the distribution of petrol, etc. If there were any people at the meeting who were under any such impression, said the President, he was sure it would be very rapidly dispelled by Flight-Lieutenant Allen. There was no doubt that the problems that had to be faced to-day by any Air Force or any air transport organisation, in connection with ground transport, were difficult enough, and in the future the problems would not become easier.

GROUND TRANSPORT FOR AN AIR ORGANISATION

BY FLIGHT LIEUTENANT R. E. H. ALLEN, A.M.I.A.E., M.I.AE.E.

1 Introduction

Probably few realise that a self-contained organisation for maintaining an air fleet would need many more different types of ground vehicles than aircraft. This is true in the case of the Royal Air Force even if all vehicles of a purely military nature are excluded. It is highly probable that a civilian air organisation of similar magnitude would have fewer types of aircraft, but if it were to be self-contained and operate in different parts of the globe, it could not do with many less types of ground vehicles than the R.A.F. finds necessary.

Obviously this depends on the interpretation of the term "self-contained." Most of the small aerial transport companies have their own ground transport organisations, but they are far from being self-contained in the sense in which the author wishes to use the term to-night. We would all like to see a vast civilian air organisation operating in and between all the different units which comprise the British Empire. Nothing would do more to knit us and the Dominions and Colonies into one impregnable whole.

But such an organisation would have to be self-contained, operating as it would in many cases in wild and uncivilised parts. Stores would have to be fed to landing grounds far from road or rail. Repairs would have to be undertaken many miles away from factory or depot. Where neighbouring tribes were hostile it might be necessary for this civil organisation to have means of

defence from raids. This is my excuse to-night for bringing to your notice many different types of vehicles.

It is inevitable that many of the vehicles referred to are R.A.F. vehicles since the R.A.F. is the only approach to a large self-contained organisation at present in existence—in this country at any rate. However, the majority of these vehicles, or similar types, would be required by a civil organisation, though in comparatively smaller numbers (since complete mobility would not be required).

2 *Commercial Types of Vehicles*

It is the aim of the Air Ministry, in the interests of economy and for easy replacement, as far as possible to make use of ordinary existing commercial

[*Crown Copyright*

Relative sinkage in sand of semi-tracked and six-wheeled vehicles.

FIG. 1.

vehicles. Obviously there is no need to design special vehicles for the conveyance of goods or passengers when there are very excellent vehicles for this purpose which can be bought in the ordinary market. Even when these vehicles are required to leave made roads and travel across aerodromes or rough country, they can still be bought in the ordinary way. This is largely due to the efforts of the War Office, to whose pioneer work in connection with rigid six-wheelers the author would like to pay his tribute. The rigid six-wheeler has been of great assistance in the reorganisation of the R.A.F. Mechanical Transport. The running costs of a light six-wheeled vehicle carrying 35 cwt. useful load are less than those of the old type four-wheeler carrying half that load. Moreover, their hauling powers are such that it is not considered unfair to expect them occasionally to pull a trailer with a similar load to their own. Of course, on certain kinds of ground their hauling abilities are not equal to those of the semi- or wholly-tracked machine, but both the initial and running costs of the latter are considerably higher.

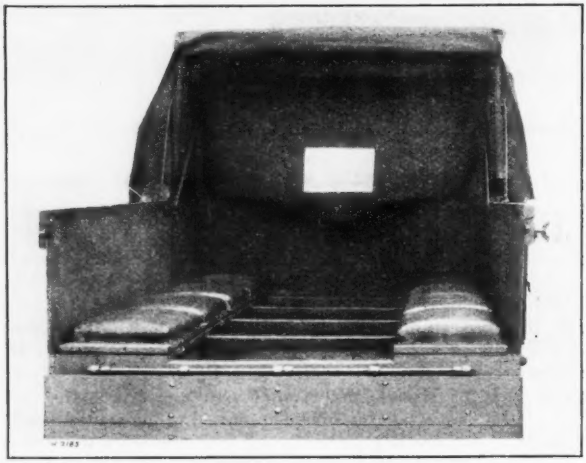
It may be accepted, then, that with certain exceptions existing commercial chassis will meet all requirements as regards prime-movers. It is in the matter of bodies and trailers that the greater departure from standard practice has to be made. But here again economy can be practised by adopting and adapting much that already exists.

Fig. 3 shows a dual purpose body. The tilt slides to allow loading by a crane. The upholstered seats for personnel can be turned over to provide a flat loading floor for engine cases or other stores, while wireless

[Crown Copyright.

Six-wheeler being towed out by Kegresse

FIG. 2.



[Crown Copyright.

Dual Purpose Body (for Stores and Personnel).

FIG. 3.

poles or other articles can be inserted in the well. Fig. 4 depicts an old and faithful friend of the service—the 3—4-tonner Leyland. Still very useful at home, it has outlived its usefulness overseas through its inability to leave made roads without getting "ditched." An attempt was made to rejuvenate

it by fitting it out with pneumatic tyres. This provides a good example of the difficulties met in any attempt to modernise an old vehicle. The fitting of giant pneumatics entailed, of course, the fitting of new hubs and wheels. The solid-tyred wheels which were discarded were of different diameters (the smaller being at the front). It was not desired to have two different sizes of tyres, so a diameter larger than the old front had to be chosen in order to approximate to the old rear wheel diameter. This gave a tilt backwards to the chassis, which was not objected to in the case of a tank vehicle. However, these changes altered the effect of the stub axle vertical pins, causing wheel wobble, which had to be corrected by altering the rake of the pins. The petrol tank, being under the driver's seat, never provided very much head of petrol to the carburettor on hills and now provided very much less, so that the introduction of an autovac became necessary. The twin wheels at the rear called for wider mudguards. The fatter section tyres made a lower-geared steering desirable, necessitating a different worm and sector.

Leyland Heavy Tender.

FIG. 4.

The moral of this is that it is better economy to buy vehicles which do not last so long and replace them at more frequent intervals so that one may keep abreast of modern developments without having to scrap, or sell at a loss, vehicles which are not yet worn out.

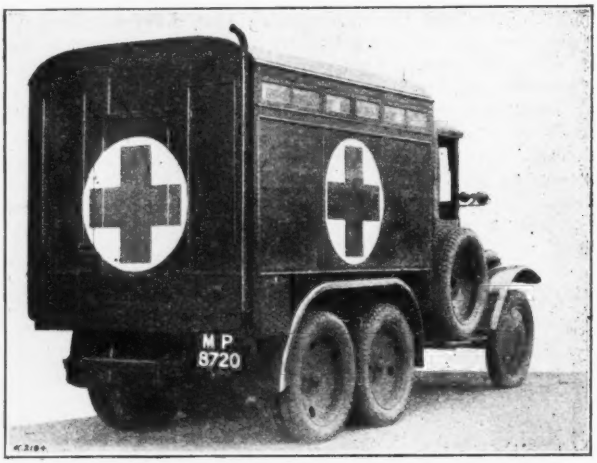
The 25/30 h.p. Crossley 15cwt. tender is now obsolescent in the R.A.F.

3 *Special "Technical" Vehicles*

The difficulty of treating this subject in a connected form or logical order will be appreciated, and it is therefore proposed to deal with the different types in alphabetical order.

(*a*) *Ambulances.*—The increase in size of aircraft makes it desirable that any ambulance used in connection with aviation should be able to accommodate at least four stretcher cases. Unless the chassis is an unnecessarily large one, this necessitates their being superimposed in pairs. This raises the centre of gravity of the vehicle. It is very desirable for the sake of the injured that the vehicle should have supple springs. The problem of rolling at once obtrudes since rough ground will always have to be traversed. Anti-rolling devices and shock-absorbers suggest themselves. The latter are seldom equally effective at both high and low speeds. The rigid six-wheeler solves the problem without any necessity for "gadgets" (Fig. 5). The Croydon ambulance, in common with

the R.A.F., accommodates the stretchers in rails into which they can be slid end on (Fig. 6). When patients are seated the rails fold up against the walls and the stretchers are stowed under the seats.



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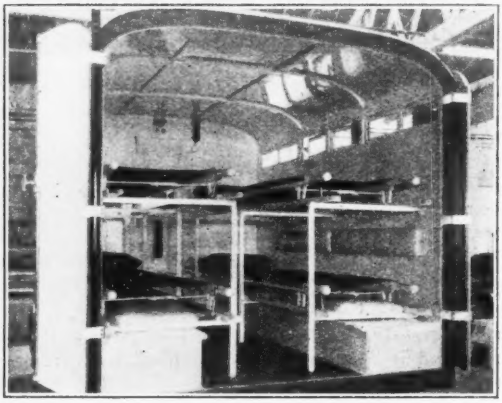
15·9 *h.p. Morris Six-wheeled Ambulance.*

FIG. 5.



Interior of Ambulance showing Collapsible Rails to take Four Stretchers.

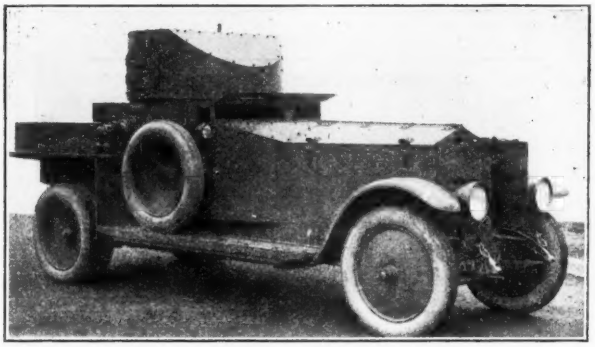
FIG. 6.

The exhaust gas must not be allowed to escape in such a manner that it may be sucked inside the body. This is very liable to happen with a body open only at the rear. It is usual, therefore, to exhaust either at the side or at the top.

(*b*) *Armament.*—It is not proposed to devote much space to this branch. Fig. 7 shows one type of armoured car. Tanks are now a familiar sight as war

memorials. They might prove useful for clearing sites for landing grounds! Other vehicles in this connection include the Leyland bomb lorry with overhead runway and a special trolley for conveying bombs with hydraulic means for raising them into position under the aircraft. A Shelvoke and Drewry freighter has also been fitted out with crane and jib for transporting torpedoes.

(c) *"Crash" Outfit.*—For many years a lorry equipped with shear legs and a certain amount of tackle and timber has been considered sufficient for salving crashed aircraft. Given plenty of ingenuity and experience on the part of the personnel, there is no doubt that the majority of crashes can be adequately dealt with in this manner. But crashes have a habit of occurring some distance from the nearest road, and aircraft have grown in size of late. The need for a more up-to-date *équipe* has been met in the following way. On the back of a four-wheel-drive tractor has been erected a crane. The jib is extensible and can be used to take out the engines of large aircraft, or for lifting the whole machine in the case of smaller aircraft. Naturally each "crash" has



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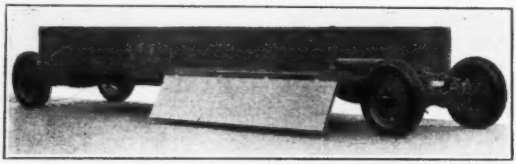
R.A.F. Armoured Car (Rolls-Royce).

FIG. 7.

to be treated in accordance with the extent of the damage. These tractors, being fitted with 38in. × 7in. pneumatic tyres, can negotiate practically any kind of rough country. Attached to them are long low-loading trailers designed to accommodate the fuselage of almost any aircraft (Figs. 8 and 9). These trailers will also traverse rough country. Some are underslung so that the frame is in the form of toboggan runners with transverse rollers to come into action in the event of the wheels sinking into soft ground. If necessary, the tractor can anchor itself on firm ground and haul in the trailer by means of its winch. The sides of the trailer are hinged and detachable, and can be used to manœuvre the wreckage on to the deck. The rollers are detachable for this purpose also. The wheelbase of the trailer shown in Fig. 9 is 23ft. 8in., yet by steering on all four wheels its turning radius is less than this. Narrow winding roads can be negotiated without special skill on the part of the driver since both axles of the trailer follow faithfully the course of the rear axle of the tractor. A plane-carrying trailer can also be attached behind the F.W.S. trailer. Shear legs, a runway, and special jacks form the equipment carried when salving very large aircraft.

(d) *Engine Starters.*—Where the elimination of surplus weight is a primary consideration the starting up of internal combustion engines is still an unsolved

problem which is being attacked from many angles. In the meantime the "Hucks" type of starter for aero engines continues to give valuable service on the aerodrome. The original type was mounted on the Ford model "T" chassis. In Fig. 10 is shown a later type evolved by Messrs. de Havilland Aircraft Co. Ltd. mounted on a Ford one-ton chassis. The transmission line is cut and the power diverted through dogs, bevels, sprocket and chain to overhead

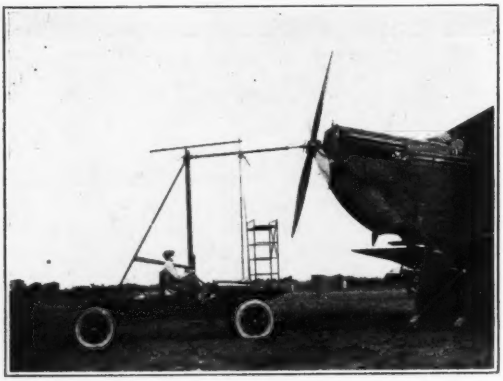


Special "Crash" Trailer (steering on all four wheels).

FIG. 8.

"Crash" Trailer, showing clean "Undersweep" for "Cross-Country" Work.

FIG. 9.



Hucks Aero Engine Starter in Action.

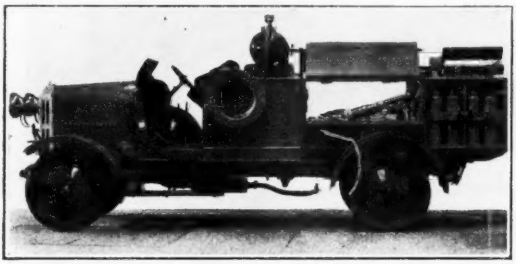
FIG. 10.

shafting which engages dogs on the airscrew boss of the machine. There is also a "Broadside" type which can run down a line of aircraft without having to manœuvre end on to each machine. A more elaborate type of starter hydraulically operated is mounted on a Crossley chassis.

(*e*) *Fire-fighting Vehicles.*—We are largely indebted to the Royal Aircraft Establishment, Farnborough, for the greatly reduced risks from fire in con-

nection with aircraft. No aerodrome authority, however, would be justified as yet in dispensing with special fire-fighting apparatus. As this must be mobile we have what is known as the fire-tender. Fig. 11 shows a more recent type employed at Croydon and many R.A.F. stations. With increase in size of aircraft, and in the quantity of petrol carried, a six-wheeled vehicle has become necessary, but cannot be illustrated here as it is still in the experimental stage. For obvious reasons no attempt is made to deal with aircraft fires by means of water; L.C.C. type motor fire engines are only used in depots or large aerodromes with many buildings.

(*f*) *Floodlight Vehicle.*—There is in use at Croydon aerodrome a special form of searchlight mounted on a Crossley-Kegresse chassis. It was originally on a hand trolley, but was found to be insufficiently mobile and therefore transferred to this chassis. It throws a 180-degree beam by means of a special lens, and its 850,000 c.p. illuminates the ground over a radius of 500 yds. It can be seen many miles away on a clear night. The 25/30 h.p. Crossley engine is used to drive the 12 kilowatt generator which supplies the current. The armature shaft forms



30-cwt. Crossley Fire Tender with Chemical Extinguishers.

FIG. 11.

part of the cardan drive to the back axle. The beam can be elevated or lowered by hand and rotated automatically (lighthouse fashion). This floodlight is a ground illuminator as distinct from the néon fog lights which have proved such a boon to Imperial Airways and foreign pilots.

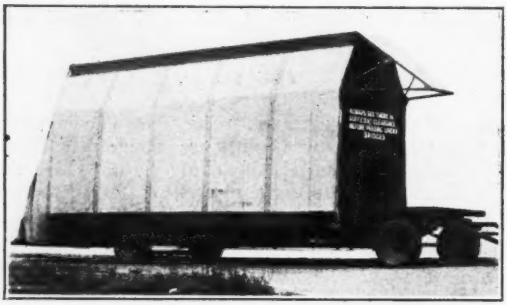
(*g*) *Photographic Vehicles.*—Photography plays an important part in both military and civil aviation. All know how aerial photographs taken behind the enemy's lines were rushed to headquarters for immediate use during the last war. You have also had papers read before this Society by experts in aerial survey work. A mobile dark room is obviously desirable. Fig. 12 shows a special body on a standard four-wheel trailer which was subjected to practical trials during the Autumn Exercises. After certain modifications have been carried out it will be sent to the Middle East. The entrance to the trailer is at the rear and steps are provided which can be carried inside when the vehicle is in motion. The interior of the trailer comprises a light-tight compartment and is intended primarily for the purpose of developing either plates exposed in the P7 camera or long lengths of film exposed in the new F8 camera. The plates are developed in the usual standard tanks over a lead-lined sink which is fitted to the near side of the interior of the trailer, the sink, as well as a bench alongside, being arranged to fold down flush with the wall when not in use. Under this sink and on the floor are placed the three 22-gallon tanks for the purpose of F8 film development. These stand on a lead base which is provided with suitable draining facilities. Beside the sink is a large storage

cupboard capable of storing the equipment. Underneath is installed an electric lighting set with an Austin 7 engine as prime-mover. This is isolated from the interior, but is accessible from the outside by hinged panels at the front and side. The set is fitted with a Ford radiator and is complete with switchboard. Its function is to provide lighting for the interior of the trailer and for the enlarging apparatus and printing machine. These latter, although carried in the vehicle, are used in a light-proof marquee which is also carried inside the trailer. A large water storage tank is placed inside the dark room and filled by means of a suction pump and external rubber hose. This pump may also be used for filling a small service tank over the collapsible sink. The trailer is ventilated by means of a suction fan.

[Crown Copyright.

Mobile Photographic Outfit.

FIG. 12.



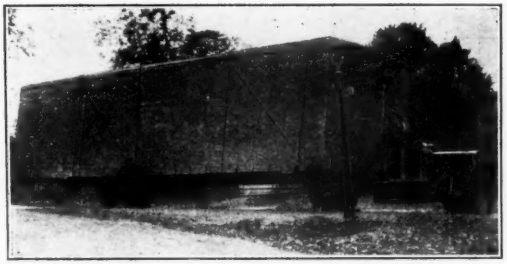
Trailer for Large Planes.

FIG. 13.

(*i*) *Plane Carriers.*—Planes are not the easiest type of stores to transport. It is to be hoped—from the point of view of those responsible for their transportation—that planes will not continue to increase in size, or if they do, that they will be in the form of handy sections. Fig. 13 shows a four-wheeled trailer originally designed for Handley-Page wings. This has already had to be increased in height for other types. Fig. 14 gives a good example of the tasks we are sometimes set. It is an R.A.F. Leyland short chassis and trailer transporting a Supermarine flying boat to the docks for the Far East Flight. The case measures 50ft. 4in. long, 10ft. 7in. wide, and 12ft. 10in. high. The whole outfit weighed 13 tons 7 cwt. and measured 62ft. 6in. by 11ft. by 16ft. 2in. high.

A special route had to be surveyed to avoid having to go under bridges. Outfits of this nature are best kept in a sheltered place during such gales as have been experienced recently!

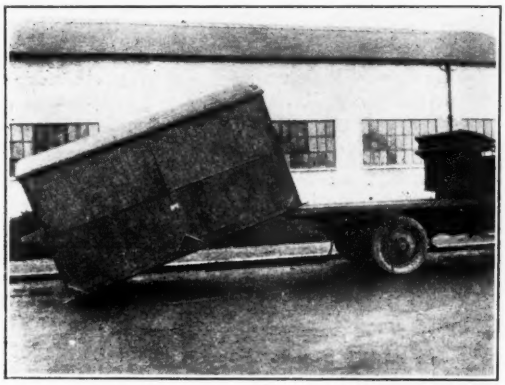
Side racks for small planes can be seen on the Leyland lorry in Fig. 4. Larger planes would be carried on a float lorry. Two-wheeled trailers with plane cases are also in use.



Giant Supermarine-Napier "Southampton" flying boat being transported by road to the steamer for shipment to Far East.

FIG. 14.

(*j*) *Store Vehicles.*—A mobile storehouse has obvious uses. It would be wasteful to mount it on a prime-mover when it would be stationary for nine-tenths of its life. In the R.A.F., therefore, such bodies are built on trailer chassis. Experiments have been made with easily detachable bodies. Fig. 15 shows one



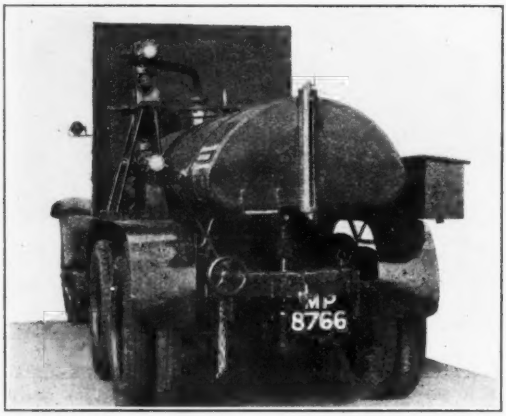
[*Crown Copyright.*

Detachable Mobile Store-house.

FIG. 15.

being slid off a chassis preparatory to its being shipped or stood on "toad-stools" (for preservation from damp or white ant) in order to release the chassis to act as a float for other purposes. For depot use a low-loading trailer has many advantages.

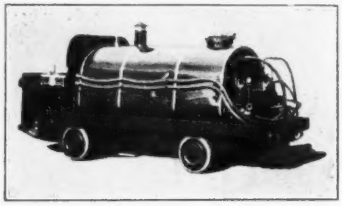
(*k*) *Tank Vehicles.*—(i) *Petrol.* Petrol tank lorries are now a familiar sight on our roads. One of the problems of which we have not yet a satisfactory solution is the provision of means of very rapidly filling an aircraft with perfectly filtered petrol from a mobile tank, at the same time knowing exactly how much petrol is being transferred. Measuring devices accurate for a varying rate of flow up to fifty gallons a minute are cumbersome and expensive. Frothing and variation in the slope of the machine make it difficult to use the gauge on the aircraft's tank. Yet it is very desirable that the pilot should be able to check his machine's consumption. Fig. 16 shows one way out of the difficulty.



Tilting Petrol Tank on Morris Six-wheeler (for Aerodrome use).

FIG. 16.

(ii) *Hot Water and Oil.* A great deal of time and petrol is wasted when a water-cooled aero engine has to "tick over" for a quarter of an hour or more before it can be "revved" up. Easy starting and a rapid "get away" are ensured if radiators can be filled with hot water and oil tanks with hot oil. Fig. 17 shows Messrs. Shelvoke & Drewry's design of vehicle to meet this need.



S.D. Hot Water and Oil Tanker.

FIG. 17.

A well-lagged boiler is heated by powerful blowlamps. Inside the boiler is an oil tank heated from contact with the water. A power-take-off in the transmission line is used to drive a Rotoplunge pump to fill or empty the boiler and a gear-type pump to fill or empty the oil tank. The tank can be slid on to a stand, leaving the freighter free for other uses.

(iii) *Drinking Water.* The desirability of providing pure water in certain parts of the globe needs no emphasis here. The R.A.F. has in use a 110-gallon W.D. type watercart and a 300-gallon type trailer. Purification of water can be effected by heat, filtration or chemical means. In the vehicles mentioned water is pumped through canvas filters before undergoing chemical treatment

[Crown Copyright.

Kegresse Aerodrome Tractor (with lifting and towing gear folded out of use) Demonstrating Stability.

FIG. 18.

[Crown Copyright.

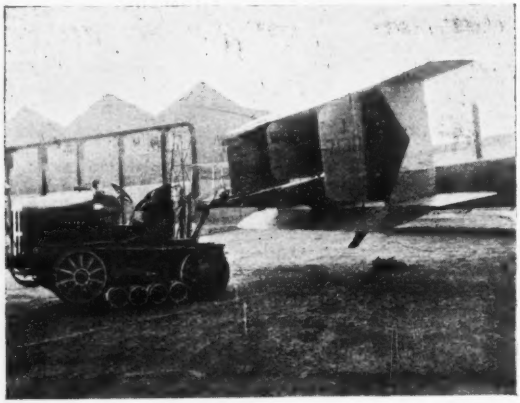
Kegresse Tractor Towing large Bomber from Undercarriage.

FIG. 19.

with bleaching powder in the tank. The metal cylinders shown contain wire cages round which the canvas is tightly wound. The cylinder head contains a fine wire gauze receptacle through which the water must pass. In this is placed a certain quantity of a mixture of aluminium sulphate and sodium carbonate. The water passing through the cylinder head takes up the chemical and deposits

a gelatinous layer on the surface of the canvas filter. With clear water it is unnecessary to use the clarifier.

(*l*) *Tractors.*—The moving of large aircraft about the aerodrome and into and out of hangars requires some form of tractor. Large bodies of men are not always available, nor are they an economical proposition. The ideal tractor for this purpose is one that is equally efficient on mud, grass, concrete, sand, or other surface. It must be able to turn in its own length, otherwise it will not easily manœuvre aircraft and will not be able to get out of a corner of a hangar after stowing the aircraft. The R.A.F. at one time used the Clayton and Shuttleworth paraffin tractor. This, having metal tracks, is unpopular on account of the damage it does to the surface of the aerodrome and hangar aprons. A rigid six-wheeler is ruled out on account of its large turning circle. (Excessive rolling of the tyres will occur if the mean wheelbase is less than about three times the pitch of the rear bogie axles.) The best solution so far appears to be the Kegresse type of



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Special Hydraulic Tail-Lifting and Towing Apparatus in Action.

FIG. 20.

tractor without a front axle. Fig. 18 shows a telescoped Crossley chassis mounted on these rubber tracks. Figs. 19, 20 and 21 show it handling aircraft in three different ways—towing from the front by cable from the undercarriage, towing or pushing by means of a special fitting on the tail, and towing by means of a tailskid trolley. In the event of excessive drag through the landing wheels sinking in a soft part of the aerodrome, it is advisable, in the two latter methods, to relieve the fuselage of stress by running cables to the undercarriage as well. The special fitting on the tail referred to above consists of a horizontal tube in the end of the fuselage into which a steel bar can be inserted. This is gripped by a special jib hydraulically operated on the back of the tractor. This is free to swivel and sprung in all directions so that no torsion or shock can be transmitted to the fuselage by the tractor. The double ram (operated by oil pressure) gives the end of the jib a range from 16in. off the ground to 7ft. 6in. The tractor is steered (with an ordinary steering wheel) by braking either track and can swivel about its own axis. It is also provided with a power-driven air-compressor (1,000 lbs. per sq. in.) for pumping up Oleo type "legs" and tyres. Oil is mixed with the air by inserting a special "bottle" in the end of the pipe-line

and inverting it as required. The S.D. freighters are fitted with similar apparatus.

(*m*) *Workshop Vehicles.*—Workshop lorries or trailers were a familiar sight behind the lines during the last war. They may be said to fall into two main types—(i) those which are mounted on lorries and make use of the lorry engine to drive the workshop plant, etc., and (ii) those which have a separate engine to drive the plant. The R.A.F. have developed a mobile workshop which is divided between two trailers. Power for the lathe and drilling machine, etc., is provided by an Austin engine (coupled to a $4\frac{1}{2}$ kilowatt generator) installed in the other vehicle. One trailer thus freed from vibration facilitates accurate workmanship. The sides, of course, open out to increase the deck space and provide an awning. When the vehicles are put together end on, quite a large workshop

[*Crown Copyright.*

Aerodrome Tractor Towing by means of Tail Skid Trolley.

FIG. 21.

results. In one vehicle is placed bench, forge, anvil and lighting set; in the other, lathe, sensitive driller and tool chest. Each machine is fitted with its own individual motor.

(*n*) *Wireless Vehicles.*—Mobile wireless stations are of more value to Scotland Yard and the military than to a civil organisation. Nevertheless, it is not difficult to imagine a set of conditions under which such vehicles would be useful to an air line. There are two types of wireless vehicles in use by R.A.F. units.

(i) A semi-portable remote-control ground station mounted on a 30 cwt. chassis towing a light trailer. The one end of the station is equipped with a petrol-electric set for power supply and a number of wireless-telegraphy or radio-telephone transmitters (according to the requirements of the particular type of squadron or unit). Normally there are three transmitters in all. The other half of the station is fitted with W/T or R/T receivers corresponding to the transmitters in use. The tapping keys or microphones for the control of the transmitters are also fitted in the receiving half of the station, and connected to the transmitter by a multi-core cable which is carried on a drum in one of the vehicles. The reasons for the division of the station into two vehicles are:—(*a*) To allow more than one channel of communication to be used at a time the receivers must be separated from the transmitters. The lay-out described allows three or four channels of communication to be working simultaneously.

(*b*) The receiving end of the station is required to be located on the aerodrome and as only 30ft. masts are necessary to support the receiving aerials, undue flying obstruction is avoided. The transmitting end requires 70ft. masts and these can be placed some distance from the aerodrome. The two ends of such a station normally work about 400 yards apart.

(ii) A portable radio-telephony station mounted on a light chassis of good "cross-country ability" and fitted with a collapsible wireless aerial. This station is entirely self-contained in the one vehicle and is capable of communicating with aircraft while the car is on the move. The vehicle is required to accompany Army units or formations with which aircraft are co-operating, and must therefore be capable of negotiating almost any sort of terrain. Three types have been developed: (*a*) an ordinary four-wheeler (now obsolete); (*b*) a semi-tracked vehicle (Kegresse type); (*c*) a six-wheeled vehicle. The last is expected to prove the most satisfactory (its greater speed being a useful quality) and is shown in Fig. 22.

[*Crown Copyright.*

Radio-Telephony Station mounted on Six-wheeled Chassis.

FIG. 22.

4 *Miscellaneous*

An extremely useful, though rather costly, vehicle is the Ransomes Rapier petrol/electric mobile crane. It might be called a "mechanical working party" since it is equally useful for shifting coke or installing an aero engine. The generator is driven by a 12 h.p. Galloway engine. Having turntable steering, it is very manœuvrable and able to turn in its own length.

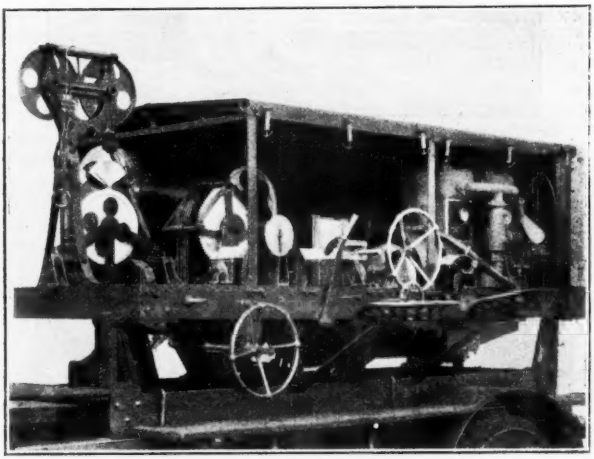
Another type of winch vehicle is the old F.W.D.-Scammell winch lorry seen in Fig. 23. This was used for observation balloons during the last war. A more elaborate type fitted with a Roadless type metal semi-track is being developed for use with airships.

Motor rollers may seem a luxury but probably pay for themselves by saving undercarriages from damage. The cutting-up of aerodrome surfaces by the tailskids of large aircraft presents a considerable problem.

A large organisation must have some means of salving its own transport vehicles. An old type of vehicle set aside for this purpose is shown (in Fig. 24) salving a "crashed" lorry. This type of tackle could, of course, be rigged on almost any float lorry.

For the collection and delivery of small stores or luggage and for postal work a light economical van is desirable. In the R.A.F. a Trojan van has been found to consume annually less in spares for upkeep than a sidecar combination. Ford vans are used by the Imperial Airways.

Two examples of Army "cross-country" staff cars are the Morris six-wheeler and Kegresse shown in Figs. 25 and 26. Something of the sort might well be needed by a civilian organisation operating overseas.



Scammell Balloon Winch.

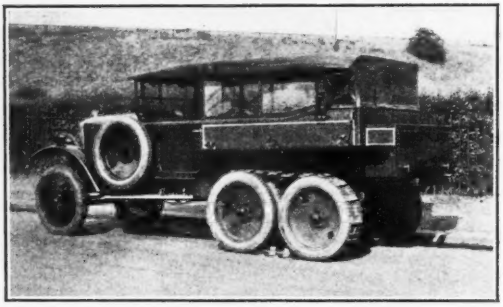
FIG. 23.

[*Crown Copyright.*

M.T. Salvage Outfit.

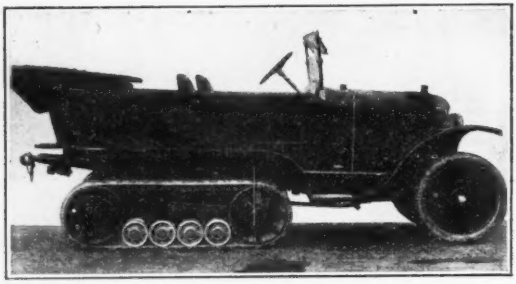
FIG. 24.

Fig. 27 shows a mobile liquid air plant for the production of oxygen for high altitude flying. Machines with airtight cabins making use of favourable winds at high altitudes have often been prophesied. Mobile or not, some sort of plant for the production of oxygen might then be required. One method of producing liquid oxygen is to compress air in a 4-stage compressor (van Hoek) to 3,000 lbs. per sq. in. Caustic soda is then used to eradicate all carbon dioxide,



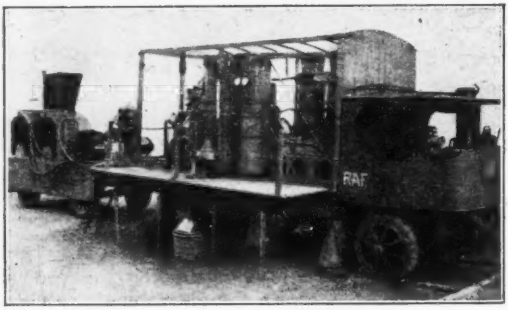
15.9 *h.p. Morris "Cross-Country" Staff Car.*

FIG. 25.



Kegresse Staff Car.

FIG. 26.



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Portable Liquid Air Plant.

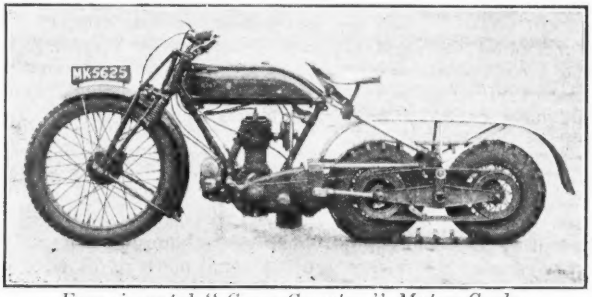
FIG. 27.

water, and oil. Rapid expansion to less than atmospheric pressure causes the temperature of the air to drop to −191°C., at which it liquefies. It is then boiled by being brought into contact with compressed air in order to distil off the nitrogen. A plant of this nature will produce 17½ litres or 50 lbs. of liquid oxygen an hour. Three litres of oxygen will maintain a pilot at 20,000ft. for thirteen hours.

Finally, the motor-cycle still has its use for despatch work. For ordinary despatch work the R.A.F. propose to use a simpler and lighter type of bicycle than the P. & M. "Panther." For cross-country work a use might be found for the three-wheeler developed by the R.A.S.C. at Aldershot (Fig. 28).

5 *Tyres*

Tyres present a definite problem to those responsible for the transport of a large organisation. If every type of vehicle is to have the equipment most suited to it, standardisation becomes impossible and stocks too cumbersome with many different sizes. It may be accepted as an axiom that it is better to over-tyre than to under-tyre. The majority of load-carrying prime-movers need larger



Experimental "Cross-Country" Motor Cycle.

FIG. 28.

tyres at the rear than at the front, though other considerations call for the same size all round. It is in this direction that the rigid six-wheeler definitely scores, since the rear axle weights approximate more closely to the front axle weight than is the case with the four-wheeler. The overall chain for the rear bogie with twin tyres was a brilliant conception and has proved its worth, but we still await a satisfactory chain for single tyres. It is obviously a difficult proposition to make such a chain of light weight and at the same time to prevent it damaging the tyre walls or coming off under certain conditions, especially in the case of the W.D. type of rear bogie suspension. In the Scammell design the problem is to some extent simplified since each pair of wheels remain always in one plane. Tyres have improved to such an extent in the last few years that the need for a special armoured car tyre has considerably lessened.

6 *Materials*

The preservation of woodwork in the Tropics from deterioration and the attacks of white ant, etc., still presents a serious problem. Teak has a long life but is heavy and expensive. It is often more economical to build of cheaper material in the first instance, send the body overseas, and renew locally when necessary. The substitution of metal wherever possible is one solution. All-metal bodies have been tried and metal bolsters in place of wood are in use in the R.A.F. Many of the bodies shown have been built of armoured plywood, all seams and

edges being carefully sealed either by soldering, lapping over the metal skin, or by beading.

7 *Conclusion*

The main trend of development in specialised transport for aviation is on the following lines.

(i) To discard solid tyres for pneumatics. There is neither time nor need to dwell on this. The move in this direction has been general throughout the world during the last few years. Its economy has been well set forth in the paper delivered by Mr. Wyndham Shire on January 2nd this year before the Institute of Transport.

(ii) To make as much use as possible of trailers. Generally speaking, any vehicle which from the nature of its function will normally remain stationary should be a trailer rather than a prime-mover. Attention is now being paid to the economic value of trailers to a far greater extent than ever before.

(iii) To make use of lighter chassis more scientifically designed to withstand rough usage. It is not satisfactory to build a massive frame and hope that it will "stay put." Triangulation is preferable to much riveting.

(iv) To adopt chassis which are as efficient "across country" as on made roads. The merits of the rigid six-wheeler have been very ably explained by those who had a hand in its development and I need only say that we have had no cause to regret our decision to adopt it. The hauling ability and economy of the light type have exceeded our expectations and we do not anticipate any disappointment as to its durability.

(v) To make use of properly designed cylinder heads which, by improved turbulence, render vehicles less susceptible to the effects of a lower grade of petrol.

(vi) To adopt devices making for easier gear-changing, especially on vehicles used for "cross-country" work, where the usual methods of effecting "clean" changes are of no avail.

(vii) Wherever possible to adopt and adapt existing commercial chassis, preferably of a type already in use for other purposes, rather than design a special chassis for the job. It is usually a more economical proposition, helps standardisation, and simplifies stocking of spare parts.

(viii) To make use of less robust chassis cheaper in first cost and maintenance, rather than expensive chassis of long life. This enables them to be used to the full, discarded after four or five years, and replaced with up-to-date design. The vehicle which has been in use for ten or twelve years has usually consumed many spares, is not economical in petrol and oil, and has prevented one having a more efficient and modern vehicle for the last five or six years. That specialised transport of all kinds has developed rapidly in the last two or three years was shown by the 1927 Commercial Motor Show—one of the most interesting shows ever staged at Olympia or elsewhere. There is little doubt that developments will continue equally rapidly during the next few years.

As an example of the efficiency of a modern medium-priced vehicle, brief particulars of a test carried out by the author are given in the Appendix.

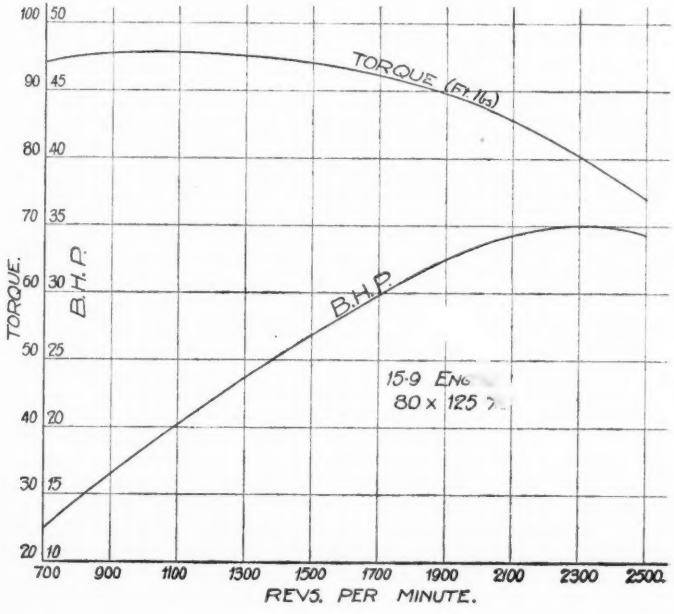
(ix) To provide greater comfort for drivers and crew, windscreens and cosier cabs are now being fitted to many of the vehicles illustrated. In the Tropics double hoods and special ventilating arrangements have been found necessary. Some will say that this is a soft and degenerate age, others that greater efficiency may be expected from men who work under better conditions.

It remains for me to say that the opinions expressed in this paper are my own and not necessarily official.

I will take this opportunity of stating that the R.A.F. is very much indebted to the British vehicle manufacturers. They have not always reaped the profit they have deserved from their enterprise, yet, speaking personally, I have always found them helpful and friendly to a degree. Finally, I would like to put on record my gratitude to all who have so willingly assisted me to obtain slides, films, and data for this paper.

Appendix

Two modern light six-wheeled vehicles of a tare weight each of 2 tons 16 cwt. were loaded with 30 cwt. useful load in addition to driver and "second man." The engines were rated at 15.9 h.p., their bore and stroke being 80 and 125 mm. respectively. Their power curve is given below. They each hauled a loaded four-wheeled trailer whose gross weight was three tons. The convoy was driven across London and then along the Great North Road for a distance of 115 miles in all. This distance was covered in 8¼ hours' running time giving an average speed of 14 miles an hour. Bearing in mind that this route is of a very undulating nature and that London was crossed from one end to the other at the worst time as regards traffic congestion, it will be conceded that this was a remarkably good performance. The vehicles were taken from stock and not specially tuned. The return journey was performed in a similar manner. Although (by means of an auxiliary gearbox) the vehicles had eight forward speeds, once London traffic was left behind, gear changes had to be made on the average only once in every two miles. A complete record of every gear change was made at the time. The low set of gear ratios had only to be used when the outfit was baulked on a gradient by other traffic. The petrol consumption was nine miles per gallon. Between 20 and 25 miles per hour could be maintained on good level roads. No boiling occurred. No adjustments of any sort had to be made. About three-fourths of the power available was used most of the time.



Obviously it would not be fair to expect such comparatively low-powered vehicles to haul such loads regularly, and allowance must be made for the good conditions under which the test was run. At the same time it should be borne in mind that taking, say, 10 b.h.p. per litre out of a modern engine is quite moderate, for it is only fifteen per cent. of what can be taken out of a petrol engine to-day. Although I know of no authority for so doing, let us assume that the useful life of an engine is in inverse ratio to the average b.h.p. which it gives off. Let us also assume that the super-efficient racing engine only lasts 500 hours. At six hours a day for 5 days a week this engine would last for thirteen weeks. If our reasoning were correct our 15.9 engine at 10 b.h.p. per litre would last about $2\frac{1}{4}$ years. This is not long enough. It is reasonable to argue, therefore, that drawing such loads should not be too frequent a practice. Volumetric efficiency must, to some extent, be sacrificed for the sake of longevity and a margin of safety. The makers of a low-loading commercial vehicle regularly carrying a useful load of $4\frac{1}{4}$ tons with a prime-mover rated at 13.2 h.p. per cent. inform me that no trouble whatever is experienced and that the vehicles give every satisfaction.

The reading of the paper was followed by two cinematograph films illustrating the operation of vehicles and attachments, including the Sparshatt sliding tilt, Morris six-wheeler, the Kegresse aerodrome tractor, the Hathi four-wheel-driven military trailer, the Scammell rigid six-wheeler, and the Kegresse rubber creeper tracks fitted to a Crossley vehicle. The films also illustrated the outstanding achievements of the various vehicles in conveying loads over trackless, hilly and swampy country.

Discussion

The President, after extending a hearty welcome to Major E. G. E. Beaumont (President of the Institution of Automobile Engineers) and to other distinguished members of that Institution who were present at the meeting, said one definite idea which came to his mind, after watching the film, was that the people who had been responsible for the design of the vehicles illustrated should be taken from the automobile industry and placed in the aircraft industry. If they could design an undercarriage which would stand in small measure the severe treatment that those vehicles would stand, pilots need no longer fear damage to that part of an aeroplane. Flight-Lieutenant Allen's paper had set down for the first time the many difficult conditions which had to be met by the ground transport of the Royal Air Force. Flight-Lieutenant Allen had been very careful to point out that the views he had expressed were quite unofficial, but one could be quite certain that, inasmuch as he held a responsible position at the Air Ministry, the views he had expressed reflected fairly clearly the present policy of the Royal Air Force with regard to this large problem. The President expressed regret that Flight-Lieutenant Allen had not broadened his paper and touched upon the seaplane tender services and all the various facilities that had to be provided in dealing with seaplanes and flying boats that were fortunately increasing in numbers.

Sir Sefton Brancker expressed the great interest which he had taken in the lecture. It was of particular interest to him because he was personally concerned in drawing up the establishment of motor vehicles for the Royal Flying Corps before the war. He had thought then that the Flying Corps had been too well done in the way of mechanical transport, but after seeing the galaxy of vehicles in use at present he had come to the conclusion that they had been rather badly done. Actually, on the Western Front the establishment proved excessive whilst trench warfare prevailed. In Egypt and Palestine, where considerable movement took place, the actual equipment proved unsuitable for the heavy sand

and mud which were encountered. He was glad to see from the photographs shown that the introduction of the six-wheeler had overcome all these difficulties. So far as civil aviation went, two classes of vehicles were required: first, a few special vehicles, such as ambulances, fire-fighting cars, and tractors carrying floodlights for work on aerodromes; and secondly, vehicles used in the ordinary routine work of the operating companies. In the latter category in civilised countries local transport could always be found; in uncivilised countries, motor transport was not much use, and salvage would often have to be carried out by air.

A big factor in civil aviation was the difficulty of supplying intermediate landing grounds with fuel and stores in undeveloped countries. For instance, a route had been proposed running through Central Persia, but one of the great disadvantages to this route, as compared with the route along the Gulf, was the great expense involved in delivering fuel and stores to the aerodromes owing to the high cost of transport from the coast. On the route between Cairo and Cape Town similar difficulties would be encountered on certain sections. Mr. Samuel Evans, a leading light in the gold-mining world in South Africa, and a great exponent of the through Cairo-Cape Town air service, was urging that a road should be made as far as possible along this route. If this was done, it would undoubtedly be of great assistance in supplying fuel and spares, but he hoped that the Colonies concerned would not spend all their money on the road and forget the air service. He was a keen supporter of the employment of tractors as a means of saving labour in moving machines about an aerodrome. We had not, so far, used an efficient tractor at Croydon, but the little Citroen Kegresse had proved to be a great success in France. One of the great problems at Croydon was the preservation of the surface of the aerodrome in the proximity of the tarmac, and already on the new site great difficulties were being caused by mud. This damage to the aerodrome was caused principally by tailskids, and he was a keen advocate of the use of a wheeled tailskid which he hoped would shortly be tried out. This, combined with a tractor, would save a great deal of labour and wear and tear, both to the aircraft and to the aerodrome.

Finally, it must always be remembered that any money spent on ground organisation, including motor vehicles, would eventually fall on the cost per ton-mile of flight by air. With this fact in mind, he was always somewhat obstructive when people suggested various improvements on the ground, such as the use of these various special type motor vehicles. The slogan of air transport must be "no forced landings"; the rôle of operating companies was transport by air, and the less money spent on transport on the ground, the better.

Colonel T. M. HUTCHINSON (Mechanical Transport Advisor to the India Office) said he was impressed by the large variety of ground vehicles used by an air organisation, and it had occurred to him that the supply of spares to those vehicles might be a very difficult matter in wartime. It therefore appeared desirable to reduce the number of types as far as possible by simplification and standardisation. The Army, he believed, and particularly the Indian military mechanical transport, were endeavouring to reduce the number of types. Many different types of body seemed necessary for special purposes, but every effort should be made to standardise a few chassis upon which the various types of body could be fitted. He was not altogether sure of the universal efficacy of trailers. For instance, he believed during the Great War the French had started with the idea of using a large number of trailers, but as the war proceeded it was noticed that they did not appear to find the trailer of such universal use as they originally hoped it would be. It was true that some vehicles, such as those used as storehouses, workshops, etc., had to remain stationary for considerable periods, also the problems of the Royal Air Force are possibly somewhat different from those of the Indian Army, so that the question of mobility may not enter into

the problem to the same extent. There might be occasions, under military conditions, when vehicles had to be moved at short notice. At such times the tractor necessary for pulling the trailer might be otherwise engaged, and thus the trailer would have to be abandoned with possibly some very valuable equipment. The construction of a trailer involved wheels, chassis, frame, springs, etc., and by the addition of the transmission gear, the motive unit and controls, it became an independent self-contained vehicle which could be driven away when necessary, so that there would be no possibility of the motive part being detached for some other purpose at a critical moment. He was interested in Air Vice-Marshal Sir Sefton Brancker's remarks in regard to the development of roads in conjunction with aircraft services. Motor transport interests would be glad to hear that roads were still so necessary.

Captain KUHNE (War Office) expressed appreciation of Flight-Lieutenant Allen's very comprehensive review of the transport problems of the Air Ministry. He would like to be permitted to join Flight-Lieutenant Allen in paying a tribute to the manufacturers of mechanical transport vehicles in this country for what they had done since the war to co-operate with the fighting services in the development of new types of vehicles, strongly aided by the capable assistance of the technical press. The user of vehicles in this country was naturally somewhat conservative, and the policy of the War Office had been to try to develop a type of vehicle which would appeal to the commercial user and which would also come nearer to military requirements in time of war. That had led, first of all, after the war, to the development of the 30cwt. subsidy type of lorry on pneumatic tyres, and subsequently—within the last two or three years—to the six-wheeled type of vehicle. The performance of that vehicle on the road was astounding, as was shown by the appendix to Flight-Lieutenant Allen's paper, and its performance across country was well demonstrated by the films which had been shown. The War Office offered a subsidy for a certain type of six-wheeled lorry. It was true, as was stated in the paper, that in these days, when types of vehicles changed quickly, machines might become obsolete in the Services before they were worn out. That was a very real difficulty. It was suggested in the paper that vehicles might be made less robust, but he (Captain Kuhne) wondered whether Flight-Lieutenant Allen really meant that, or whether he meant that they should be a little less durable in wearing parts, and a little less expensive to make. Flight-Lieutenant Allen would probably agree that these vehicles must at least be robust if they were to be of any use to the Services. It was clear that if the Government Departments which used mechanical transport wanted the manufacturers to produce the types of vehicles which would suit their purposes, there must be inter-departmental co-operation; otherwise, they would confound the manufacturers with a diversity of requirements which could never be met. He was glad to be able to say that co-operation between the Departments was very close. They had Committees to help them in that work, but they were helped, perhaps even more, by personal interchange of opinions in their efforts to make it as easy as possible for manufacturers to standardise production. One could not help coming to the conclusion that radical changes in the types of chassis which the Departments wanted the manufacturers to produce could not occur every year. Perhaps those who did not appreciate the difficulties of the manufacturers were inclined to say, "We had an advance about eighteen months ago, when you produced the six-wheel lorry; now what about the next step?" He felt, however, that it was necessary to face the fact that such radical changes could only occur at intervals of several years. In the interim they could perfect the types of vehicles that had been taken into the Service, and experiment for the next advance. That gave manufacturers time not only to perfect their designs, but to market their vehicles commercially. The six-wheeler was coming into quite large production, and the War Office hoped it would come into extensive use at home, in order to give them a reserve. The peace-time holding

was not enough to go to war with. A considerable number was being sold at the present time, and though the bulk was going overseas, a steadily increasing number was coming into commercial service at home. The main thing was that the vehicles were in commercial production, and when it was appreciated that only two years had elapsed since the first experimental machines were produced, one might be well content with the situation. Commenting upon Colonel Hutchinson's remarks as to the diversity of equipments used by the Air Ministry, he said he felt quite sure that the Air Ministry were pursuing the same lines as the War Office, *i.e.*, to standardise as much as possible the bodies and the chassis. It was clear from the illustrations which had been given that much of the specialised equipment could be, or actually was, fitted to the same type of chassis.

Mr. H. KERR THOMAS (Past President of the Institution of Automobile Engineers) said he had been very much instructed by the paper, which was almost a liberal education in the design of specialised bodies. Colonel Hutchinson appeared to be fearful of the multiplicity of designs, but it appeared to him (Mr. Kerr Thomas), after reading the paper, that the tendency was in the other direction. Broadly speaking, the vehicles were really only of two types, or need only be of two types, if one excepted the heavy tractor for haulage purposes on aerodromes. He had concluded that the four-wheel vehicle, as we had known it, for the purposes of an air organisation must be almost extinct, because it was obvious that service to aircraft must almost invariably be given in inaccessible places. One could not decree, for instance, that if a crash occurred it must be within 20ft. of a high road, and the problem seemed to boil down, therefore, to the abandonment of the four-wheeler and the use of the rigid six-wheeler. Judging from the photographs which had been shown, it appeared that only two sizes were required—one with a carrying capacity of about 30cwt., and the other of three or four tons. If either of those was a six-wheeler, which would negotiate almost anything that could be negotiated, we had advanced a great deal since the days when the only vehicle which could get to positions which were difficult of access was a track vehicle. Referring to the appendix of the paper, he said he rather differed from the author in one respect. He had not hitherto come across the relationship which was mentioned between the horse-power and the life of the engine; in fact, he would have thought it was rather the other way about. It was pretty well an accepted fact, he believed, that a high efficiency engine had a longer life than one of the other type. In the diagram in the Appendix, which appeared to refer to a typical engine, there was a torque of 95 ft. lbs., an equivalent of a brake mean effective pressure of 93, but that was rather low nowadays. There were plenty of engines of all types in commercial vehicles now which were operating with brake mean effective pressures of from 105 to 110, which meant that a still smaller engine than the 80 × 125 m.m. engine could be employed. A point which the author had not mentioned, but which might usefully have been put forward, was that, inasmuch as the vehicles had to operate in more or less inaccessible places, some attention would have to be given to the use of air-cooled engines. The use of water-cooled engines in places where water was almost unobtainable meant introducing a new difficulty, and it seemed to him that very soon manufacturers would have to pay a good deal more attention to the production of an air-cooled lorry engine than they had done in the past.

Major E. PARTRIDGE, Office of the High Commissioner for India, India Store Department, referring to the author's statement that it was better economy to buy vehicles which did not last so long and replace them at more frequent intervals, said it would be interesting to have some facts and figures to support this statement at a later date, say, after twelve months' running. So far, no one had referred to the cost of maintenance, or the number of hours during which a vehicle might be off the road for minor repairs. That was important; a

machine might last for a considerable period, but during that period it might be off the road a good deal for minor and major repairs, whereas a more costly vehicle might seldom be off the road for repairs. Referring to Colonel Hutchinson's statement that the use of trailers had been found by the French to be unsuccessful, and the suggestion that they were rather a costly makeshift, he said his own experience of the Great War was that trailers were extraordinarily useful, quite a large number of unofficial ones being in use by units with complete success. As to the suggestion that the addition of a power unit, etc., would not increase the cost much, the argument being that there was little difference in cost between trailer and lorry, such was not the case, the trailer being a cheaper proposition. In any case many trailers and loads could be abandoned to the enemy in case of sudden advance without great loss if the towing vehicle was mobile. If self-propelling vehicles were used in place of trailers, the prime movers might be stationary for quite long periods of time, and it might be that if a vehicle was required to move suddenly the prime mover might be found unready to function, many instances having occurred where a prime mover never turned over for months on end. Dealing with the construction of bodies, he said that one of the greatest difficulties he had to face in India was to find materials for their construction which would withstand the unusual climatic and other conditions and the stresses imposed upon the body material by the modern six-wheeler. Suggestions had been made as to the use of materials other than wood, such as metal, plymax, etc., and information as to the use of such materials would be of great interest. It was understood that the Air Ministry had used the latter material in Mesopotamia and Transjordina with complete success.

Colonel NEAME, speaking as a representative of one of the manufacturers who had done a good deal of business with the Government Departments, said that the relations between them had been always most friendly, and he had always received every assistance from the War Office, the India Office and the Air Ministry. Referring to the author's suggestion that sometimes the enterprises on which manufacturers were encouraged to embark were not entirely remunerative, he agreed that that was so, but taking a broad view as taxpayers we ought to congratulate the Government Departments on their very keen desire to economise.

Mr. LAWRENCE KING (Morris Commercial Cars, Ltd.) said the author had brought out a fact which he was sure very few people had realised, namely, that the Royal Air Force, just as much as the Army, depended to a very large extent on the efficiency of its mechanical transport. When one studied the various problems which had to be faced by the R.A.F., one came to the conclusion that practically all of these could be met by the use of the rigid six-wheel chassis—the light, medium and heavy types. It would not be going too far to describe this vehicle as a connecting link of vital importance. If we could get down to the use of a standardised vehicle in the Army, the R.A.F., and in commerce, then the cost would be considerably reduced. In his opinion the six-wheel vehicle was the only one built which complied with both military and civil requirements, and the vital importance of having great numbers of machines to draw upon in cases of national emergency applied to the R.A.F. as well as to the Army. Discussing fire-fighting appliances, he said that there was in production a fire engine mounted on a six-wheel chassis, which was giving very great satisfaction under conditions such as those which the R.A.F. would require to meet. The test of the R.A.F. vehicles, described in the Appendix to the paper, was extremely interesting, and he believed that very large transport users in this country would soon recognise the very low cost of these vehicles per ton-mile.

Major P. M. SANDERS (Technical Editor, *Motor Transport*) asked the author if he could give any recent figures relating to the costs of running four-wheel and six-wheel vehicles, because he knew a lot of people who did not believe that the six-wheeler could be run at a cheaper rate than the four-wheeler. Commenting on

the author's reference to the use of a motor roller for keeping the surface of an aerodrome in good condition, he said it had occurred to him that if the use of a fairly heavy tractor was necessary on an aerodrome it could be in such a form that it could consolidate the ground and make its own road. In the construction of the Kingston by-pass road a number of track machines had been used which were extremely effective in consolidating the ground. Discussing the preservation of woodwork, he referred to the recently invented process by which wood and other materials were coated with a very thin coating of metal, and in the course of the process a certain amount of interpenetration took place, so that the coating would not peel off. He suggested that if that process were used it might be most valuable. Referring to the author's reference, at the end of the Appendix, to the performance of a certain low-loading commercial vehicle, he said that, as a kind of life member of a society for the prevention of cruelty to internal combustion engines, it appeared to him that the use of 13.2 h.p. to move $4\frac{1}{4}$ tons at any speed at all was really asking for trouble. Possibly, however, that particular vehicle had very small wheels, and was designed to travel at a rather low speed, and of course had a rather low gear.

Captain W. H. SAYERS said that aeronautical engineers who had not had much to do with the motor vehicle trade could not but be amazed at the versatility of the vehicles which had been illustrated. He had seen pictures of six-wheelers before, and had realised that they represented a very remarkable engineering development, but he had not realised that they were capable of such performances as had been demonstrated by the cinematograph films. It seemed to border on the indelicate that it should have been left to the Royal Aeronautical Society to show that the R.A.F. had in use a much larger variety of vehicles than of aircraft.

Major E. G. E. BEAUMONT (President of the Institution of Automobile Engineers), who wound up the discussion, agreed that the author had performed a valuable service in bringing so vividly before the meeting the complexity of the road transport necessary in an air organisation. Even those who had had some connection with this work must have learned something from the illustrations which had been presented. The paper also emphasised the importance of standardising types as far as possible, so that the burden of expenditure upon a commercial organisation might be reduced to the minimum. Like Mr. Kerr Thomas, he had taken the trouble to summarise the types mentioned in the paper, and had concluded that among the twenty or twenty-one types of vehicle referred to, not more than twelve need be used for a commercial air organisation as distinct from a Service organisation. Furthermore, by using dual type vehicles—trailers or interchangeable bodies—the number of types of chassis might be reduced to perhaps half a dozen, which was not a considerable number, and compared very well with the diversity of types needed by other transport organisations. In that respect he agreed with Mr. Kerr Thomas that with the multi-axle vehicle, there was a probability of effecting a compromise which would go some distance towards solving the problem. He used the term "some distance" because, having had the advantage of seeing the R.A.S.C. vehicles going through their performances, he had realised that, wonderful though those performances might be, in any long distance service defects would inevitably develop. In fact, on the single occasion on which he had witnessed the working of these vehicles under very severe conditions, whilst the rear portion had given no trouble whatever—and he was informed by R.A.S.C. officers that there was very little mechanical trouble at all—nevertheless damage of the front axle or steering gear had occurred. Difficulties of that sort, however, were by no means beyond solution, and one came to the conclusion that a useful compromise might be made. With regard to the use of trailers, Major Beaumont expressed the view that trailers would be used more frequently if the regulations governing that class of vehicle were such as to give a little more

encouragement. At the present time a speed of five miles per hour was the legal limit. All who used trailers travelled at at least ten miles per hour, and if they could travel at fifteen miles per hour there would be a greater incentive to use such vehicles—and with perfect safety if they were of the right type. Discussing the Appendix to the paper, he agreed with previous speakers who had suggested that an attempt to economise in engine size would probably prove to be a bad policy. The author's figure of 10 b.h.p. output per litre of capacity might be compared with about 6 or $7\frac{1}{2}$, he supposed, as representing good commercial vehicle practice, and yet with that latter relation it was found that for road transport rates of working the engine required attention and repair at least twice as often as the rest of the vehicle. Therefore, he considered that if one tried to economise in engine size one would reap a harvest of greater engine trouble. Referring to the extraordinarily large bodies used for the transport of bulky parts, such as the wings or fuselage of a Handley Page aeroplane, Major Beaumont said that the dimensions of one body mentioned were 50ft. length, 10ft. width and 16ft. height, and he asked what was the total weight, *i.e.*, the weight of the vehicle and of the load it carried.

Reply to Discussion

Referring to the Chairman's suggestion that motor boats and other transport facilities connected with seaplane and flying boat organisations might have been dealt with, he said he did not think they came within the title of the paper, and in any case it would be difficult to include an adequate reference to water craft in the necessarily limited time available at this meeting. With regard to the cutting up of the surface of aerodromes by the tailskids of aeroplanes, referred to by Air Vice-Marshal Sir Sefton Brancker, he said he was very pleased to hear that there was a possibility of wheel tailskids being adopted, and he imagined that one of the things that would help to bring about the adoption of such skids as much as anything would be the fitting of brakes to the landing wheels of aircraft, as some substitute would be needed for the tailskid cutting into the surface of the aerodrome to bring about quick deceleration. Replying to Colonel Hutchinson, he said that if there were an impression that there were many different types of vehicle in use in connection with aircraft organisations it might be due to the fact that he had shown some examples of obsolete vehicles as well as modern vehicles. Of course, the ground transport was in process of reorganisation, and it was not possible to scrap everything at once. It was beyond question that the tendency was to reduce the number of types, and the rigid six-wheeler had helped in that respect in a manner which no other vehicle could have done. He was rather glad that Mr. Kerr Thomas had thought the torque curve shown in the Appendix to the paper did not show very high m.e.p., because it strengthened his point that if this work could be done with an engine such as that indicated, a great deal more could be done with the same engine if the m.e.p. were increased, and there was no doubt that the m.e.p. could be increased very much by the type of combustion head that was designed to improve turbulence and flame rate. He heartily endorsed Mr. Kerr Thomas's reference to air cooling, and only wished that there was a good air-cooled engined vehicle on the market to-day. There had been one, but it seemed to have disappeared from view. He would welcome it if it were a commercial proposition, but, true to the policy outlined, the Air Ministry were trying to adhere to the type of vehicle now on the road, and that was the only reason they had not gone in for air cooling. The six-wheel fire engine referred to by Mr. Lawrence King was, presumably, one which pumped water, and water was not the best medium for extinguishing petrol fires. Replying to Mr. Sanders's request for some recent figures concerning the running costs of six-wheelers and four-wheelers, he pointed out that in the paper he had stated distinctly that the six-wheeler was very much

more economical than the *old type* of four-wheeler. It was very difficult indeed to obtain exactly comparable figures of petrol consumption, for instance. With a 30cwt. four-wheel vehicle he considered he was doing quite well to obtain eleven miles per gallon, whereas thirteen miles per gallon was obtained from 30cwt. six-wheelers. Of course, the two vehicles were not truly comparable, because one had a smaller engine than the other, but the speeds were the same, and they were comparable in that respect. The remarks on the Appendix made by Mr. Kerr Thomas and Major Beaumont were diametrically opposed. This was also true of Colonel Hutchinson's and Major Partridge's comments on the usefulness of trailers. He did not think, therefore, that further comment was needed from him on these two matters. With regard to the weights asked for by Major Beaumont, they were approximately $4\frac{1}{2}$ tons for the vehicle and nearly 9 tons for the load. With regard to the reference to " lack of robustness " by Captain Kuhne in his very valuable contribution to the discussion he would like to say that what he had in mind was the very wonderful service given by the Ford which though adequately " strong " could hardly be called " robust."

In conclusion, he would like to thank Major Sanders for his suggestion that a heavy tractor might also act as a roller for the aerodrome. It struck him as a very practical proposal.

SUMMARIES OF TECHNICAL PUBLICATIONS RECEIVED

(Prepared by the Editor)

Aerodynamics

Resistance of Streamline Wires. George L. De Foe. N.A.C.A. Technical Note, No. 279. March, 1928.

SUMMARY.

Contains results of tests to determine the resistance of four sizes of streamline wires made at various speeds. Scale effect was also found since, with an increase of Reynolds number, a decrease in the resistance coefficient was obtained.

The Importance of Streamlining in Relation to Performance. Professor B. M. Jones, M.A., A.F.C. H.M.S.O., 9d. September, 1927. R. & M., No. 1,115 (Ae. 288).

SUMMARY.

A statement by Professor Jones that the time has come when more attention should be given towards improving performance. He comes to the conclusion that the most hopeful line of attack is that directed towards obtaining a better streamline flow about the aeroplane than is apparently obtained at present. The improvement in streamlining is definitely retarded by lack of aerodynamic data relating to the kinds of shape which give rise to streamline flow. The present note deals with the empirical side of such an investigation which should be carried out under the ægis of the Aeronautical Research Committee.

Part I. deals with general considerations and suggestions for lines of research; Part II., comparative factors discussed and applied to existing aircraft; Part III., airscrew body interference; and Part IV., specific suggestions for experiments.

Aerofoils

Full-Scale and Model Measurements of the Lift and Drag of the Bristol Fighter with M2 Section Wings. E. T. Jones, M.Eng., and A. S. Hartshorn, B.Sc. H.M.S.O., 6d. November, 1927. R. & M. No. 1,133 (Ae. 303).

SUMMARY.

Introductory.—Full-scale and model measurements of the lift and drag of the Bristol Fighter with M2 section wings have been made to provide data on the scale effect of the thin symmetrical wing. The lift and drag of the Bristol Fighter fitted with wings of R.A.F. 15, R.A.F. 19 and R.A.F. 30 section have been measured both full scale and in the N.A.C.A. variable density wind tunnel. The full-scale measurements with M2 section wings extend the comparison between the results obtained in the variable density tunnel and free flight tests.

Range of Investigation.—The lift and drag coefficients have been determined full-scale over as wide a range of incidence as possible (2° to 20°). Wind tunnel experiments on a 1/10th scale model have been made over a slightly larger incidence range at wind speeds of 40, 60 and 80 ft./sec.

Conclusions.—The maximum lift coefficients for full-scale and model are 0.432 and 0.38 respectively. The minimum drag coefficient decreases as the Reynolds number increases, being 0.0315 at 40 ft./sec. on the model and 0.028 full-scale. The results are in quite good agreement with those of the N.A.C.A. variable density tunnel.

A High-Speed Wind Channel for Tests on Aerofoils. T. E. Stanton, F.R.S. H.M.S.O., 9d. January, 1928. R. & M. 1,130 (Ae. 300).

SUMMARY.

Reasons for Inquiry.—A request from the Airscrew Panel for tests on aerofoils at speeds in the neighbourhood of the velocity of sound.

Tests were carried out in the modified N.P.L. 3 in. high speed wind channel at speeds ranging from 0.25 to 1.7 times the velocity of sound.

The increase in the scope of the lift curve without appreciable change in the angle of no lift as the speed increases up to 0.6 of the velocity of sound, predicted in R. & M. 1,135, has been verified. The limiting speed at which the effect ceases appears to be considerably higher for the circular arc aerofoil tested than for the R.A.F. 31a, but in both cases when the limit is reached the lift falls rapidly for higher speeds and the angle of no lift tends to zero value. At speeds considerably above the velocity of sound (1.7a) the angle of no lift has a negative value for R.A.F. 31a and a positive value for the circular arc aerofoil.

Model Experiments with Rear Slots and Flaps on Aerofoils R.A.F. 31 and R.A.F. 26. H. B. Irving, B.Sc., A. S. Batson, B.Sc., and A. L. Maidens. H.M.S.O., 6d. November, 1927. R. & M. No. 1,119 (Ae. 292).

SUMMARY.

Aerofoils of sections R.A.F. 31 (with front slot) and R.A.F. 26 (without front slot) were fitted with rear slots formed by the gap between flap and main portion and the best position of flap when at 20° to main wing found.

With R.A.F. 31 experiments were limited to one shape of slot, but in R.A.F. 26 three variations were tried.

Results.—Rear slot on R.A.F. 31 gave a maximum lift coefficient with flap at 20° and front slot open of nearly 1.2, over double that of original aerofoil. Rear slot itself gave an increase in lift coefficient of 0.15 with front slot open and flap at 20°. With flap at 0° and front slot closed the rear slot increased the minimum drag by about 10 per cent., but no appreciable alteration in maximum lift/drag ratio. Maximum lift with flap at 20° and front slot open occurred at 18.3° compared with 23.8° incidence on the aerofoil with front slot, but without flap, and 12.3° on the original unslotted aerofoil.

On R.A.F. 26 the highest lift coefficient obtained was 0.753 (original 0.485). Increase in minimum drag was only 2 per cent.

In all cases maximum lift is much more sensitive to changes in flap position which alter the width of the slot than to change in direction parallel to the slot. Choice of hinge position so as to bring the flap to the best position when set down is important.

The Effect of Compressibility on the Lift of an Aerofoil. H. Glauert, M.A. H.M.S.O., 6d. September, 1927. R. & M. 1,135 (Ae. 305).

SUMMARY.

The effect of the compressibility of the air on the characteristics of an aerofoil moving at a velocity approaching that of sound is of fundamental importance for the design of high-speed airscrews, and an attempt has been made, therefore, to develop a theory for the lift of an aerofoil at high speeds.

As the speed increases to 0.6 of the velocity of sound, the slope of the lift curve increases without any change in the angle of no lift. There is then a critical region in which the lift falls fairly rapidly until at the velocity of sound the lift curve is again a straight line with the same general slope as at low speeds but passing approximately through zero angle of incidence.

These general theoretical conclusions are in agreement with the experimental evidence available, and suggest that the most satisfactory aerofoil shape for high-speed airscrews might be a symmetrical section.

Aeroplanes

The Aircraft Handbook. F. H. Colvin and H. F. Colvin, New York and London. 1928. 3rd edition.

CHAPTER HEADINGS.

1, Simple Airplane Theory. 2, Rigging the Plane. 3, Assembling Curtiss J.N. 4's. 4, The Propeller. 5, The Airplane Engine. 6, Trouble Shooting for Airplane Engines. 7, Wright Whirlwind Engines. 8, The Curtiss D-12 Engine. 9, Packard Aircraft Engine. 10, Pratt and Whitney Wasp Engine. 11, The Liberty Engine. 12, The Curtiss O.X. Engine. 13, The Wright-Hispano Engine. 14, Aircraft Instruments. 15, Air Commerce Regulations. 16, Construction of Air Ports. 17, Nomenclature for Aeronautics.

Aeroplanes—Full Scale

Pressure Distribution on Wing Ribs of the VE-7 and T.S. Airplanes in Flight. Part II. Pull-ups. R. V. Rhode. N.A.C.A. Technical Note No. 277. January, 1928.

SUMMARY.

The second of a series of notes, each of which presents the complete results of pressure distribution tests made on wing and rail ribs of the VE-7 and T.S. airplanes for a particular manœuvre of flight. The results for pull-ups are presented in the form of curves which show the variation of pressure distribution, total loads, normal acceleration and centre of pressure with respect to time.

In general, it is concluded from these results that in pull-ups:—

(1) Maximum loads on upper and lower wing ribs occur simultaneously, but the upper wing load is always greater than the lower wing load.

(2) The horizontal tail surfaces experience a considerable down load which occurs previous to the maximum wing load.

(3) The elevator never experiences an up load, and the up loading on the stabiliser is never great.

(4) The intensity of the down loading on the elevator is greater than on the stabiliser, but local pressures on the stabiliser are greater than those on the elevator.

(5) The centre of pressure on the upper wing of a biplane moves abnormally far forward by an amount which cannot be pre-estimated by existing wind tunnel data.

Aeroplanes—Model Experiments

Tests on Models of Three British Airplanes in the Variable Density Wind Tunnel. G. J. Higgins, W. S. Diehl and G. L. De Foe. N.A.C.A. Report No. 279. Washington, 1928.

SUMMARY.

Models tested, BE2E with R.A.F. 19 wings and Bristol Fighter with R.A.F. 15 and R.A.F. 30 wings.

Tested over a wide range of Reynolds numbers. Maximum lifts obtained in these tests are in excellent agreement with published results of British tests, both model and full-scale.

Lift and Drag of Three Model Aeroplanes. Comparative Tests in Atmospheric and Variable Density Wind Tunnels at the same Reynolds Number. H. C. H. Townend, B.Sc. H.M.S.O., 6d. June, 1927. R. & M. 1,122 (Ae. 295).

SUMMARY.

Lift, drag and pitching moment were measured on all the models (without tail units) from zero to maximum lift. The results from the variable density tunnel are compared with those obtained in the atmospheric tunnel, and also with a few full-scale results obtained from other sources.

The results, regarded as a comparison between experiments in two different tunnels, are in excellent agreement. The ability of the variable density tunnel to yield results applicable to full-scale with fair accuracy is also apparent.

Models tested, BE2E with R.A.F. 19 wings; Bristol fighter model with R.A.F. 15 wings and R.A.F. 30 wings.

Aeroplanes—Performance

The Effect on Performance of a Cut Away Centre Section. T. Carroll. N.A.C.A. Technical Note No. 273. Washington, 1928.

SUMMARY.

The assumption is made that a skeleton or cut away centre section is desirable for forward vision and to determine its effect the following work was done.

The aeroplane used was a Vought VE7 and in adddtion to the cut away centre section a system of end plates or fins was installed. Various conditions and combinations were investigated in level flight and in climb.

It is found that the greatest difference in the conditions investigated was a drop of 12.5 per cent. in a ten-minute climb, while the effect upon level speeds was negligible.

Aeroplanes—Strength

An Analysis of Some Causes of Discrepancies between the Calculated Failing Load of the Structure of an Aircraft and the Load at which Failure Occurs on Strength Test. H. B. Howard, B.A., B.Sc., and K. T. Spencer, B.Sc., Assoc.M.Inst.C.E. H.M.S.O., 6d. August, 1927. R. & M. 1,125 (Ae. 298).

SUMMARY.

Records of mechanical tests on complete structures, components and materials have been analysed and compared with calculations on the structure and the strength values for the material assumed in calculations.

No reliable conversion factors for relating the strength as calculated with that obtained on test can be established without considerably more test data than are at present available.

Aeroplanes—Wings—Pressure Distribution

Pressure Distribution Tests on P.W.9 Wing Models showing Effects of Biplane Interference. A. J. Fairbanks. N.A.C.A. Report No. 271. Washington, 1927.

SUMMARY.

The conclusions may be summarised as follows:—

(1) The effect of the biplane interference on the pressures of individual wings is almost entirely restricted to the lower surface of the upper wing and the upper surface of lower wing.

(2) The distribution of the normal force along the span of the individual biplane wings is not greatly different from that along the span of the same wings tested individually. That variation, which is apparent, is caused by the fact that the overhanging tip of the upper wing is relatively little influenced.

(3) The wash-in of the centre section of the upper wing, where the chord is reduced, presents a large reduction of the normal force across the portion of the wing, providing the airfoil section is not mutilated.

(4) The upper wing of the biplane buckles at the same angle of attack at which it buckles when tested individually. The buckle of the lower wing of the biplane occurs at an increased angle of attack relative to that at which it buckles when tested as a monoplane.

(5) The overhanging tip of the upper wing causes the lateral centre of pressure to be farther out along the span than it is when the wing is tested as a monoplane. At large angles of attack the centres of pressure are moved forward by the biplane interference.

Airscrews

Charts for the Calculation of Airscrew Thrust and Torque Coefficients. J. D. Coales, D.Sc. H.M.S.O., 6d. September, 1927. R. & M. No. 1,114 (Ae. 287).

SUMMARY.

Eight years ago charts were produced to simplify calculations of the thrust and torque coefficients of airscrews. Theory of airscrews was not then so well established as now and the charts were not published because of the discrepancies found to occur between the calculated and full-scale values of torque coefficients. Charts are based on the same equations that occur in the modern vortex theory of airscrews as given in Glauert's Aerofoil and Airscrew Theory. The curves enable the thrust and torque coefficient to an airscrew at a particular value of V/nD to be obtained with a minimum of trouble.

The Characteristics of Airscrew Section R. & M. 322, No. 4, and R.A.F. 32. W. G. A. Perring, R.N.C., A.M.I.N.A. H.M.S.O., 6d. January, 1928. R. & M. 1,134 (Ae. 304).

SUMMARY.

The general results of both sections are similar to those obtained in previous tests. Both sections have exceptionally large drag at high speeds, and the conventional airscrew section compares very unfavourably with the thinner section of the same type previously tested. At speeds above 0.7 of the speed of sound, both sections pass through a critical stage, when the characteristics appear to depend both on the Reynolds number and the actual speed.

The Characteristics of a Conventional Airscrew Section, Aerofoil R. & M. 322, No. 3, at High Speeds. G. P. Douglas, D.Sc., and W. G. A. Perring, R.N.C. H.M.S.O., 9d. September, 1927. R. & M. 1,124 (Ae. 297).

SUMMARY.

Present experiments continue those described in R. & M. 1,086 and 1,091. General results are similar to those of R.A.F. 31a and bi-convex sections previously tested. For speeds up to 0.8 of the speed of sound the conventional type of section is practically as good as any section previously tested and at and above 0.9a it appears to be slightly inferior to the bi-convex No. 2 section. The importance of the Reynolds number of the element under test possibly affords

an explanation of the good lift results obtained in the original experiments (R. & M. 884) with similar, but not identical, sections.

Wind Tunnel Tests with High Tip Speed Airscrews. The Characteristics of Bi-Convex No. 2 Aerofoil Section at High Speeds. G. P. Douglas, D.Sc., and W. G. A. Perring, D.N.C. H.M.S.O., 9d. September, 1927. R. & M. 1,123 (Ae. 296).

SUMMARY.

Present experiments continue those described in R. & M. 1,086 and 1,091.

The general results are similar to those of the R.A.F. 31a and bi-convex section previously tested, but the bi-convex No. 2 section is better than the thicker and less cambered original bi-convex section at all speeds, and is better than the R.A.F. 31a section at and above 0.8 of the speed of sound. The results for the present section and previous sections tested are compared with those for a conventional airscrew section in R. & M. 1,124.

Analysis of Experiments on an Airscrew in Various Positions within the Nose of a Tractor Body. C. H. H. Lock, M.A. H.M.S.O., 1s. 0d. September, 1927. R. & M. 1,120 (Ae. 293).

SUMMARY.

Methods of R. & M. 956, modified, have been applied to the analysis of the experimental results of R. & M. 1,030.

Conclusions.—The mutual influence of airscrew and body includes (*a*) an effect of the body on the torque for given V/nD, with an " effective " efficiency equal for given torque to the efficiency of the exposed portion of the blades calculated without interference, and (*b*) the slipstream effect on the body drag as defined in the paper. For a body of normal size (*a*) is very small and only (*b*) is of importance.

Determination of Propeller Deflection by Means of Static Load Tests on Models. F. E. Weick. N.A.C.A. Technical Note No. 275. January, 1928.

SUMMARY.

Describes a simple and inexpensive method for determining the deflection of propeller blades under operating loads. Both the centrifugal force and air force loads are applied statically as a number of concentrated loads by means of weights and wires. Two methods of attaching the wires to the propeller blades have been tested, both giving approximately the same deflections. The method is considered useful for studying the deflections of propellers of different shapes under various operating conditions.

The Effect of the Sperry Messenger Fuselage on the Air Flow at the Propeller Plane. F. E. Weick. N.A.C.A.Technical Note No. 274. January, 1928.

SUMMARY.

In order to study the effect of the fuselage, landing gear, and engine on the air flow through the propeller, a survey was made in the plane of the Sperry Messenger propeller with the propeller removed. The tests were made in the 20ft. air stream of the propeller research tunnel of the N.A.C.A. at Langley Field. The variation of the velocity with distance from the centre in the propeller plane was found to be appreciable and well worth consideration in the design of propellers. It was also found that the velocity through the propeller plane was affected by the pressure of the engine, and that the velocity in front of the landing gear was lower than that at other points in the propeller plane having the same radius.

Autogyro

Lift and Torque of an Autogyro on the Ground. H. Glauert, M.A. H.M.S.O., 4d. July, 1927. R. & M. No. 1,131 (Ae. 301).

SUMMARY.

Introductory.—A request was received for the lift and torque of an autogyro windmill driven by an engine at various r.p.m. when standing on the ground in winds of 0, 10, and 20 m.p.h. at angles of incidence of 8°, 10°, and 12°.

Range of Investigation.—The lift and torque have been derived for any windmill in the static condition, and the equations are given for calculating these quantities in a wind of 20 m.p.h., one particular numerical case being worked out in detail. The values for a wind of 10 m.p.h must be estimated by interpolation as the theory is not valid for so low a speed.

Conclusions.—In the static condition the lift is very small, and in a wind of 20 m.p.h. the lift is proportional to the tip speed. At a given tip speed the lift increases and the torque decreases as the angle of incidence rises from 8° to 12°.

Bodies

Drag of Exposed Fittings and Surface Irregularities of Airplane Fuselages. D. H. Wood. N.A.C.A. Technical Note No. 280. March, 1928.

SUMMARY.

Measurements of drag were made on fittings taken from typical fuselage to determine whether difference between the observed full-size fuselage drag and model fuselage drag could be attributed to the effects of fittings and surface irregularities on the full-size fuselage and not on the model.

The measurements show that a large part of the difference between model and full-scale test results may be attributed to these fittings.

Bombs and Ballistics

The Gaseous Explosive Reaction—The Effect of Inert Gases. F. W. Stevens. N.A.C.A. Report No. 280. Washington, 1927.

SUMMARY.

Attention is called in the paper to previous investigations of gaseous explosive reactions carried out under constant-volume conditions, where the effect of inert gases on the thermodynamic equilibrium was determined. The advantage of constant-pressure methods over those of constant-volume as applied to studies of the gaseous explosive reaction is pointed out, and the possibility of realising for this purpose a constant-pressure bomb is mentioned.

The application of constant-pressure methods to the study of gaseous explosive reactions, made possible by the use of a constant-pressure bomb, led to the discovery of an important kinetic relation connecting the rate of propagation of the zone of explosive reaction within the active gases, with the initial concentrations of those gases. The inert gases investigated were N_2, He, and CO_2.

Congresses

Proceedings of the Second International Congress for Applied Mechanics. Zurich, 12-17 September, 1926. Leipzig, 1927.

Contains, in English, the following:—The distortion of single crystals of metals, G. I. Taylor; Some mechanical properties of matter under high pressure, P. W. Bridgman; The control of stalled aeroplanes, B. M. Jones; The use of models in the solution of indeterminate structures, G. E. Beggs; Stress concentration produced by fillets and holes, S. T. Timoshenko; An experiment on the behaviour of two vortices in water, S. Fujiwhara; Discontinuous fluid motion past curved barriers, S. Brodetsky.

Engines

The Performance of Several Combustion Chambers Designed for Aircraft Oil Engines. W. F. Joachim and C. Kemper. N.A.C.A. Report No. 282. Washington, 1928.

SUMMARY.

Comparison of the data presented shows that the precombustion chamber type cylinder head, arranged to provide controlled, high-velocity air turbulence as in cylinder head No. 3, gave the best engine performance. It is concluded that the type of cylinder head gave the highest indicated mean effective pressures and the lowest fuel consumptions per i.h.p. hour with the lowest cylinder pressures at all loads and speeds in these tests, because the most thorough mixing of the fuel and air was obtained and high cylinder pressures were prevented by this cylinder head design.

Equal and even superior engine performance has been obtained with integral combustion chamber type cylinder heads, but the cylinder pressures were in excess of those for the precombustion chamber type cylinder head.

These tests indicate that improvement in the performance of aircraft oil engines depends primarily upon the complete mixing of well-atomised fuel with the air charge in precombustion chamber type cylinder heads and, in addition, upon the prompt ignition of the fuel in integral combustion chamber type cylinder heads.

The Relative Performance Obtained with Several Methods of Control of an Over-Compressed Engine Using Gasoline. A. W. Gardiner and W. E. Whedon. N.A.C.A. Report No. 272. Washington, 1927.

SUMMARY.

From these comparative tests it may be concluded that, of those methods investigated for controlling an over-compressed engine using gasoline under sea-level conditions, maximum power is obtained by maintaining full throttle and greatly retarding the ignition timing. Also, as the fuel consumption, exhaust temperatures, and heat loss to the cooling water are normal, and as this method of control is easily accomplished without adding to the complexity of the power plant, it may be considered the most practicable method for service use.

Throttling of the carburettor with, approximately, full normal ignition advance gives the best economy of the various methods, but the least power. Varying the timing of the inlet valve with, approximately, full ignition advance gives somewhat greater power than obtained by the throttling method, but the fuel consumption is excessive, although the values for the latter, given in this report, are higher than would be obtained with a multi-cylinder engine.

Heat Transfer in Internal Combustion Engines. H. Moss, D.Sc., A.R.C.S., D.I.C. H.M.S.O., 1s. 3d. September, 1927. R. & M. 1,129 (E. 28).

SUMMARY.

It was found that the heat transfer in unit time was proportional to the temperature difference between gas and wall and to the square root of the gas density. In the neighbourhood of 1,200 r.p.m. it was proportional to the square root of the speed, and for a more extended range to $\log(1+cn)$, where c is a constant. The coefficient of heat transfer was much greater for the suction stroke than for the remainder of the cycle.

By extrapolation, the heat conducted from gas to walls when running under power was found to be about one half of the total heat losses, the remainder being due to radiation. The total heat losses are also proportional to the square root of the gas density. The increase of the temperature gradients in the metal when an engine is supercharged is not important and the increase of valve tem-

perature is small. The error involved in the method of phase setting of indicators by means of motoring curve is less than one quarter of a degree of crank angle.

Motoring Losses in Internal Combustion Engines. H. Moss, D.Sc., A.R.C.S., D.I.C. H.M.S.O., 6d. July, 1927. R. & M. 1,128 (E. 27).

SUMMARY.

Results and Conclusions.—The sliding friction under power may be greater than that when motoring by the equivalent of 3.5 lb. per sq. in. M.E.P. due to this cause. With an increase of 3.5 lb./sq. in. M.E.P. found by Ricardo, due to carbonisation, the magnitude of the effect when running under power with a normal spark setting is fully explained.

Fuels

The Effects of Fuel and Cylinder Gas Densities on the Characteristics of Fuel Sprays for Oil Engines. W. F. Joachim and E. G. Beardsley. N.A.C.A. Report No. 281. Washington, 1927.

SUMMARY.

Results of investigation show that the spray penetration increases and the spray distribution, cone angle, and atomisation decrease with increase in the specific gravity of the fuel oil. The effects of applying centrifugal force to fuel sprays is pronounced. The use of centrifugal force to atomise and distribute a fuel is more important for heavy fuels than for light fuels.

The density of the chamber gas was found to control spray penetration rather than the gas pressure. The kind of gas used in the spray chamber for conditions of constant density had no measurable effect on the fuel sprays. The effect of gas viscosity was, therefore, negligible.

A composite curve for spray penetration for injection into gases varying in density as in an engine, showed about 17 per cent. greater penetration after 0.003 second than did the curve for a constant gas density equal to that at maximum compression.

Glossaries

The Aslib Directory, a Guide to Sources of Specialised Information in Great Britain and Ireland. Edited by G. F. Barwick, B.A. London, 1928. £1 1s. 0d. net.

Technical Dictionary. Fortnightly parts, 2s. 6d. net. May, 1928. Sir Isaac Pitman.

A dictionary of engineering and industrial science terms in English, French, Spanish, Italian, Portuguese, Russian and German.

Helicopters

On the Vertical Ascent of a Helicopter. H. Glauert, M.A. H.M.S.O., 9d. November, 1927. R. & M. 1,132 (Ae. 302).

SUMMARY.

Report deals only with the vertical ascent of a helicopter, and for simplicity the analysis is limited to the case of an airscrew with constant chord along the blades.

A helicopter screw should be of large diameter, in order to secure a light loading of the disc, and also of large blade area. Also to obtain the best rate of climb the blade should be adjustable in flight.

Materials

The Distribution of Stress and Strain in the Wöhler Rotating Cantilever Fatigue Test. W. Mason, D.Sc., and N. P. Inglis, Ph.D.M.Eng. H.M.S.O., 1s. 6d. October, 1927. R. & M. 1,126 (M. 52).

SUMMARY.

The following types of specimens were tested under two point loading giving uniform bending over a parallel length of 1 in. :—

Solid of 0.2 in. diameter.
Hollow, of wall thickness, $\frac{1}{32}$ in., $\frac{1}{4}$ in. bore.
Hollow, of wall thickness, $\frac{1}{64}$ in., $\frac{1}{4}$ in. bore.

The tests were directed to the following objects :—

(1) To compare the limiting ranges of solid and hollow specimens.
(2) To find the cyclic fibre strains at limiting and other ranges.
(3) To estimate the actual stress in the fatigued specimen.

Results.—A certain relation between maximum cyclic strain and applied bending moment has been found. The importance of this strain as a determining factor in relation to the endurance has been shown. The actual skin stress in thin-walled hollow specimens has been calculated and estimate made of this stress for solid bars.

Meteorology

Results of Observations on the Direction and Velocity of the Upper Air Current Over the South Indian Ocean. A. Walter, F.R.A.S. Geophysical Memoirs, No. 39. H.M.S.O., 3s. od. 1927.

The 27-Day Recurrence Interval in Magnetic Disturbance. J. M. Stagg, M.A., B.Sc. Geophysical Memoirs, No. 40. H.M.S.O., 1s. od. 1927.

An examination made with the aid of hourly character figures.

Studies of Wind and Cloud at Malta. J. Wadsworth, M.A. Geophysical Memoirs, No. 37. H.M.S.O., 1928, 2s. 6d.

SUMMARY.

Paper consists of three parts, and is based on observations of wind and cloud at the University Observatory, Valletta, and the Meteorological Office, Pieta. The first part deals with the diurnal variation of the surface wind, the second part describes the behaviour of the upper winds, and the third part contains information relative to the incidence of cloud and rain.

Electric Potential Gradient Measurements at Eskdalemuir, 1913-23. R. A. Watson, B.A. Geophysical Memoirs No. 38. H.M.S.O., 1928, 1s. 6d.

SUMMARY.

Since the start of the observatory at Eskdalemuir, the electric potential at a point near the north wall has been recorded continuously by means of a Kelvin water-dropper connected to a Dolezalek electrometer. This paper summarises the results for the period 1913-1923.

Miscellaneous

Translated Abstracts of Technische Berichte, 1917. Two vols. Air Publication 1,120-1,121.

Notation

Report of the Symbols Sub-Committee. H.M.S.O., 3d. November, 1927. R. & M. 1,142.

Gives a list of symbols approved by the A.R.C. on the recommendation of the special sub-committee appointed to consider them.

Wind Tunnels

A Comparison of Propeller and Centrifugal Fans for Circulating the Air in a Wind Tunnel. F. E. Weick. N.A.C.A. Technical Note No. 281. March, 1928.

SUMMARY.

Tests carried out afford a direct comparison of the efficiency and smoothness of flow obtained with propeller fan and multiblock centrifugal fan drives in the same wind tunnel. Propeller fan was found to be superior to the centrifugal fan in that the efficiency was about twice as great and the flow much smoother.

An Automatic Speed Control for Wind Tunnels. A. F. Zahm. N.A.C.A. Technical Note No. 278. February, 1928.

SUMMARY.

A description of the automatic control in use with the 8-foot wind tunnel at the Navy Yard, Washington.

Wireless

A Popular Guide to Radio. B. Francis Dashiell. London, 1927.

CHAPTER HEADINGS.

1, The development of radio. 2, A study of electricity and magnetism. 3, The sources of the electric current. 3, The fundamental principles of radio. 5, The use of radio antennæ and grounds. 6, The electron tube and crystal rectifiers. 7, The principles of radio amplification. 8, Radio inductance coils and condensers. 9, Important fundamental radio receiving circuits. 10, The electrical reproduction of sound. 11, Modern applications of radio transmission and reception. 12, Causes and prevention of radio interference. 13, Some essential radio apparatus and information. 14, Natural phenomena and their effect on radio operations.

REVIEWS

The Art of Flying

By Capt. Norman MacMillan, M.C., A.F.C. Foreword by Air Vice-Marshal Sir Sefton Brancker, K.C.B., A.F.C. Gerald Duckworth & Co., Ltd. 5/- net.

The first and most important comment one has to make on this book is that it must be read. If any member of the aeronautical community refrains from buying, borrowing, or stealing a copy, or from reading it, he should be classified as self-complacent.

Non-aeronautical people, who are at all alert and wish to keep in touch with the tendencies of modern progress, should be encouraged to read it in preference to penny journalism on the subject.

The book is conversational in tone and almost casual in lay-out. It is made exceedingly readable by a generous sprinkling of epigrams, generalisations and stories, all of which serve to drive home some technical or psychological point. Some are eminently quotable: " Too much imagination places unnecessary strain on the individual, while too little places unnecessary strain on the aircraft." " . . . It is better to fly in relation to the air and to ignore the ground completely." " Think on the ground first." " Undercarriage failures are very rare occurrences now, and the standard of good landings has suffered as a result." And so on. I would draw the particular attention of all pilots, experienced, budding, or prospective, to the paragraph (pp. 20 and 21) dealing with turns near the ground in a high wind. This is, so far as I am aware, the first rational treatment of the subject that has ever appeared in print. It only occupies half a page, and it is to be hoped that the author will see his way, in future editions, to amplify his explanations.

The author gives expression throughout to a keen sense of the beauty, the poetry, the splendid isolation to which flight has given man access. Why, one wonders, are most other pilots apparently oblivious to those grander qualities of the air? Are they, as a race, thick-skinned and inarticulate, or merely inarticulate?

It is a fortunate quality of this book that, notwithstanding its title and style, it leaves the impression in the mind of the reader that after all flying is rather more of a science and rather less of an art than is generally thought. This is a healthy tendency. And it provides a badly needed antidote to those curious fallacies and phobias, inherited from the pioneering days, which still prevent an amazing number of pilots from making proper use of their instruments.

A certain looseness of phraseology—difficult, perhaps, to avoid in a popular book on a technical subject—has in some instances been carried too far. For example, on p. 44 the following passage occurs: " At the lowest air speed at which *the excess in* wing lift *over the resistance of the aeroplane* is equal to or slightly greater than its total weight the aeroplane commences air-born flight." (Italics are mine.) Surely, there is confusion here! And again, on p. 123: " In the vertical turn an aeroplane obtains its wing lift from the air *through centrifugal force*. . . ." (Italics are mine.) Would it not be analogous and

equally inaccurate to say that in straight flight wing lift is obtained from the air *through gravity*?

But these are merely the sort of pin-pricks to which the reviewer resorts in order to avoid the dullness of unblended praise.

Captain MacMillan's book has done more than confirm and explain his reputation as one of the foremost test pilots in this country. It has brought to light a breezy literary talent, the further products of which will be eagerly awaited.

The Romance of Chemistry

William Foster, Ph.D. George Allen and Unwin, Ltd. 1928. 12/- net.

Dr. Foster is the professor of chemistry at Princeton University, and he has written a most readable and informative book. The book fully justifies its title, and the story he tells is one which will well repay reading. Here is little of the chemical formulæ to terrify and much of the heart of chemistry to enthral. Here the importance of chemistry in industry, in medicine, farming, and every-day life is explained not only clearly and simply, but with a human interest which raises the book above the common level of such books. It is comparable with that delightful book, " The Chemistry of Common Life," by Professor Church, which made its first appearance in the nineteenth century. A book, in short, which can be confidently recommended to those who have no knowledge of chemistry and to those who have much.

Everybody's Aviation Guide

Major Victor W. Pagé. Norman W. Henley Publishing Co., New York. 1928. $2.00 net.

This is a book covering a wide field, from the early history of aeronautics, to design and control of aeroplanes, in 229 pages. It covers the field by means of questions and answers, framed for the man in the street.

To deduce from the questions and answers given in the book the particular type of man in the street to whom Major Pagé wishes to appeal is difficult. Does the man in the street wish to know why it is not desirable to exceed the " burble " point? What influence the angle of incidence has on load carrying? What is the usual relation of parasitic resistance of various parts of the total resistance? The man in the street, who wishes to know something about aeroplanes with a view one day to becoming an owner-pilot, must be very much like the same man who intends to possess a car. And the prospective car-owner has not the slightest interest in the thermodynamics of internal combustion engines, nor does he wish to study curves showing the heat generated by the sudden application of four-wheel brakes.

Many of the questions and answers could have been very well left out of the book as far as the man in the street is concerned, and as far as the man in aviation is concerned the book is of no value. Many questions and answers are clumsily worded and the answers are incorrect. A few questions and answers will illustrate the criticisms:—

Q. What is the centre of pressure of an airplane wing?

A. The point at which the maximum lift is assumed to be concentrated is called the centre of pressure, and it is located about one-third the distance from leading edge to trailing edge on most aerofoils.

Q. Does the centre of pressure stay constant?

A. No, the pressure centre changes with each change of incidence and it is also at different points along the span of the wing.

Q. In what three planes does an airplane move?

A. An airplane moves up and down, from side to side, and also tips, so one wing-tip is higher than the other.

Q. Why are most modern airplanes " nose heavy " instead of " tail heavy "?

A. Because it is better for an airplane to go down nose first in event of engine failure than tail first.

" Everybody's Aviation Guide " should more properly have been reviewed in *Punch*, preferably with illustrations, and it is only reviewed very lightly here to serve as a guide to those who wish to avoid buying a farrago of nonsense.

Memories of Land and Sky

Gertrude Bacon. Methuen. 7/6 net.

Miss Gertrude Bacon is the well-known daughter of the late Rev. John M. Bacon, and was his companion in many of his most exciting balloon voyages. She was the first woman to make a " right away " voyage in an airship and the first Englishwoman to ascend in an aeroplane. For those reasons alone she is entitled to place her memories of land and sky on record.

It was one day in August, 1898, that Miss Bacon received the laconic telegram from her father, " Come along." " Rare luck was mine on this my first balloon voyage," she writes, " for we travelled right over the heart of London, crossing the Thames between London and Tower Bridges—the streets and houses laid out as a mighty map, while the whole air was full of a deep continuous hum, not so much as of bees in the limes as the humming drone of a distant mighty dynamo—the throb of the heart of the world." There were many balloon voyages after that, but the reviewer suspects that though they had their thrills and dangers, none of them gave the author the intense joy of that first flight.

In August, 1904, came the first flight in an airship, the third airship built by Stanley Spencer, and for the second time Miss Bacon recaptured the thrill of a first aerial experience. " I thought the voyage the most rapturous I had yet known, combining all the rare beauty of balloon travel . . . with the charm of motion, the thrilling sense of life."

Here is told the story of the Wright Brothers. " A more cultured, modest and reserved American never lived," she writes of Wilbur Wright. The names of pioneers whom Miss Bacon met are scattered thick throughout the book, " Roe the Hopper," J. T. C. Moore-Brabazon, S. F. Cody (" I sat behind him at meetings of the Aeronautical Society, and marvelled at the long curls which hung down over his massive shoulders "), C. S. Rolls, F. K. McClean, Howard Wright, Alexander Ogilvie, Handley Page, the Short Brothers, to name but a few.

Miss Bacon's description of the first flying meeting at Rheims deserves to be read by all who have become *blasé* to the air. One quotation is sufficient. " On the last day came the Height Prize, when he (Farman) and Latham climbed against each other up the sky. Latham, unperturbed, reached what even Charles Grey described as ' the awe-inspiring and perilous height ' of 500 feet; and

Farman was held to have done marvels by reaching 360; but he landed all white and shaken from the strain."

Space does not permit justice being done to a book which one is grateful Miss Bacon has written, and the only real criticism which can be made of it is that it is all too short. After Miss Bacon made her first aeroplane flight (at the Rheims meeting) she writes: "You wonderful aerial record breakers of to-day and of the years to come, whose exploits I may only marvel at and idly envy, I have experienced something that can never be yours and can never be taken away from me—the rapture, the glory and the glamour of 'the very beginning.'"